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PREPARATION OF
DATA ASSIMILATION
AND
MODEL EVALUATION
EXPERIMENT
DATA SETS

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by

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by

C. Aaron Lai

and

Wen Qian

Abstract

Under the sponsorship of the Navy Ocean Modeling and Prediction (NOMP) program, the Institute for Naval Oceanography (INO), in cooperation with the Naval Research Laboratory (NRL) and universities, executed the Data Assimilation and Model Evaluation Experiment (DAMEE) for the Gulf Stream Region (GSR) during fiscal years 1991 -- 1993. The concept of DAMEE is unique in the history of ocean modeling and data assimilation research. Enormous effort has gone into every aspect of the experiment, including the preparation of a high-quality and consistent data set for model initialization and verification. The scientific findings from this experiment are being published by DAMEE participating groups in various journals.

Due to limitations in time and manpower, not all interesting topics in the experiment were thoroughly studied. Furthermore, the techniques of data assimilation and the method of model evaluation were still being formulated when the DAMEE had to conclude. However, the data set prepared for DAMEE will prove to be a big asset in the community for future research. Therefore, a technical report about the preparation process, the temporal and spatial scopes, the contents, the structure, etc., of this data set is in order.

The goal of DAMEE is briefly stated, first, because it provides the rationale for the experiment plan which, in turn, decides the data need for the four phases of the experiment. The preparation of the DAMEE data set consisted of a series of processes: (1) collection of observational data, (2) analysis and interpretation, (3) interpolation, using the Optimum Thermal Interpolation System (OTIS) package, (4) quality control and re-analysis, (5) data archiving and software documentation.

The data products from these processes included a time series of 3-D fields of temperature and salinity, 2-D fields of surface dynamic height, 2-D bogus information of the Gulf Stream and rings system and XBT profiles. To date, they are the most detailed and high-quality data for mesoscale modeling, data assimilation and forecasting research. Feedback from ocean modeling groups (including Harvard, MIT, Princeton, Rutgers, and NRL) who tested them were incorporated into the refinement of data. It is intended to make this data set easy to access. An ideal way is to put it into a few CD-ROMs.

Suggestions for DAMEE data usage include (1) ocean modeling and data assimilation studies, (2) diagnosis and theoretical studies, and (3) comparisons with locally-detailed observations, such as those in the SYNOP project, to guide field programs.

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I. Introduction

The concept of DAMEE originated during the INO 1989 Summer Colloquium on Mesoscale Ocean Science and Prediction at the National Center for Atmospheric Research (NCAR). The idea was to help the Navy select an appropriate mesoscale ocean model and companion data assimilation scheme to be further developed into an operational forecast model system. After reviewing the inputs from the university ocean modeling community, the goals were changed to: (1) to foster a good COMMUNICATION between university ocean modeling groups and the Navy ocean modeling group, (2) to provide an opportunity for university and Navy research scientists to EVALUATE their work in ocean modeling and data assimilation, and (3) to COMPARE the strengths of different models under a uniform configuration. This concept is unique in the history of ocean modeling and data assimilation research.

In response to the need to support Navy anti-submarine warfare, and because of the importance of understanding the Gulf Stream in oceanography research, the domain of the DAMEE experiment was defined over the Gulf Stream Region. Its east, west, south and north boundaries were 47°W, 82°W, 27°N and 47°N, respectively. Other reasons for choosing this domain were the distinctive features of the Gulf Stream, the availability of more observations over this region and the existence of an operational ocean data analysis system -- the Optimum Thermal Interpolation System (OTIS) for this region.

The DAMEE was conducted in four phases, each based on different data sets (case studies) and each phase building upon the results of the previous phases. The experiment began with a May 1991 meeting of four participating modeling groups, who reached a consensus on an experimental plan and decided the cases for Phase 0 and Phase I. They also agreed on using the data prepared by INO with the OTIS package. An August 1991 workshop followed at Woods Hole Oceanographic Institution (WHOI) to exchange information on the FY91 (Phase 0) one- and two-week "OTIS-initialized forecast (OIF)" preliminary results, and to finalize the plan for the Phase I, two-week "forecast with data assimilation" assessment. In a meeting held during the Marine Technology Society (MTS) Conference on 14 November 1991, results from Phase I were presented, and a one-month case and the plan for Phase II were also discussed. At the June 1992 meeting at Diamondhead, Mississippi, the Phase II

preliminary results from some groups and all Phase I results were presented. The final Phase III plan included a two-month forecast with data assimilation. The two-month case was constructed by combining the one-month case in Phase II with one of the Phase I two-week cases and a bridging date. At a future meeting, the Phase III results and aggregate results and the conclusions are expected to be presented.

To date, four groups working on the development of mesoscale eddy-resolving models for the Gulf Stream Region have participated in the experiment. These four models are (1) the Harvard Primitive Equation Ocean Circulation Model (FLEXCAST), (2) the NRL Data Assimilation Research and Transition (DART) Model, (3) the Princeton Primitive Equation Data Assimilation Model (PEDAM), and (4) the Rutgers Semi-spectral Primitive Equation Model (SPEM), configured for the Gulf Stream Region by the MIT group. The Harvard group decided to use the intermittent data assimilation. The Optimum Interpolation (OI) data assimilation was the choice of the Princeton group. The Rutgers/MIT group carried out the nudging approach. The NRL group tried a "rubber-sheeting" approach. Table 1 illustrates the experimental plan of the four Phases.

Each participating modeling group carried the responsibility for: (1) providing a validated model, (2) conducting experimental runs with assistance from INO, and (3) analyzing results, providing reports, and participating in experiment meetings. The INO carried out an institutional role in this assessment which included: (1) coordinating the experiment planning and design, (2) providing access to INO facilities, (3) assisting modeling groups in conducting experimental runs, and (4) arranging meetings.

This report presents the preparation process and the product data sets of DAMEE in the Gulf Stream Region. The case studies in the different Phases are presented in Section II. Section III gives details about the DAMEE data preparation. It describes (1) the tools used in data analysis, especially the OTIS package, (2) the data input to the OTIS and their qualities, and (3) the data output from OTIS and their properties. Section IV describes the hierarchy of DAMEE data directories. It is necessary because of the huge volume of data sets. Section V provides some software packages to help users access DAMEE data sets. Section VI suggests some usages for DAMEE data; it is intended to contribute some

experiences to new users in the community. Summaries of the data preparation processes, their advantages, and their shortcomings are given in Section VII.

Table 1. DAMEE Experimental Plan

<u>Phase</u>	<u>Forecast Lengths</u>	<u>Initialization/Data Assimilation</u>
0	6 one-week forecasts 3 two-week forecasts	OTIS initialization, no data assimilation
I	6 two-week forecasts	OTIS initialization, with data assimilation
II	one-month forecast	OTIS initialization, with data assimilation
III	two-month forecast	OTIS initialization, with data assimilation
* * * * *		
<u>Group</u>	<u>Model</u>	<u>Data Assimilation</u>
Harvard	FLEXCAST	Intermittent data assimilation
Princeton	PEDAM	Optimum Interpolation data assimilation
Rutgers/MIT	SPEM	Nudging data assimilation
NRL	DART	Rubber sheeting

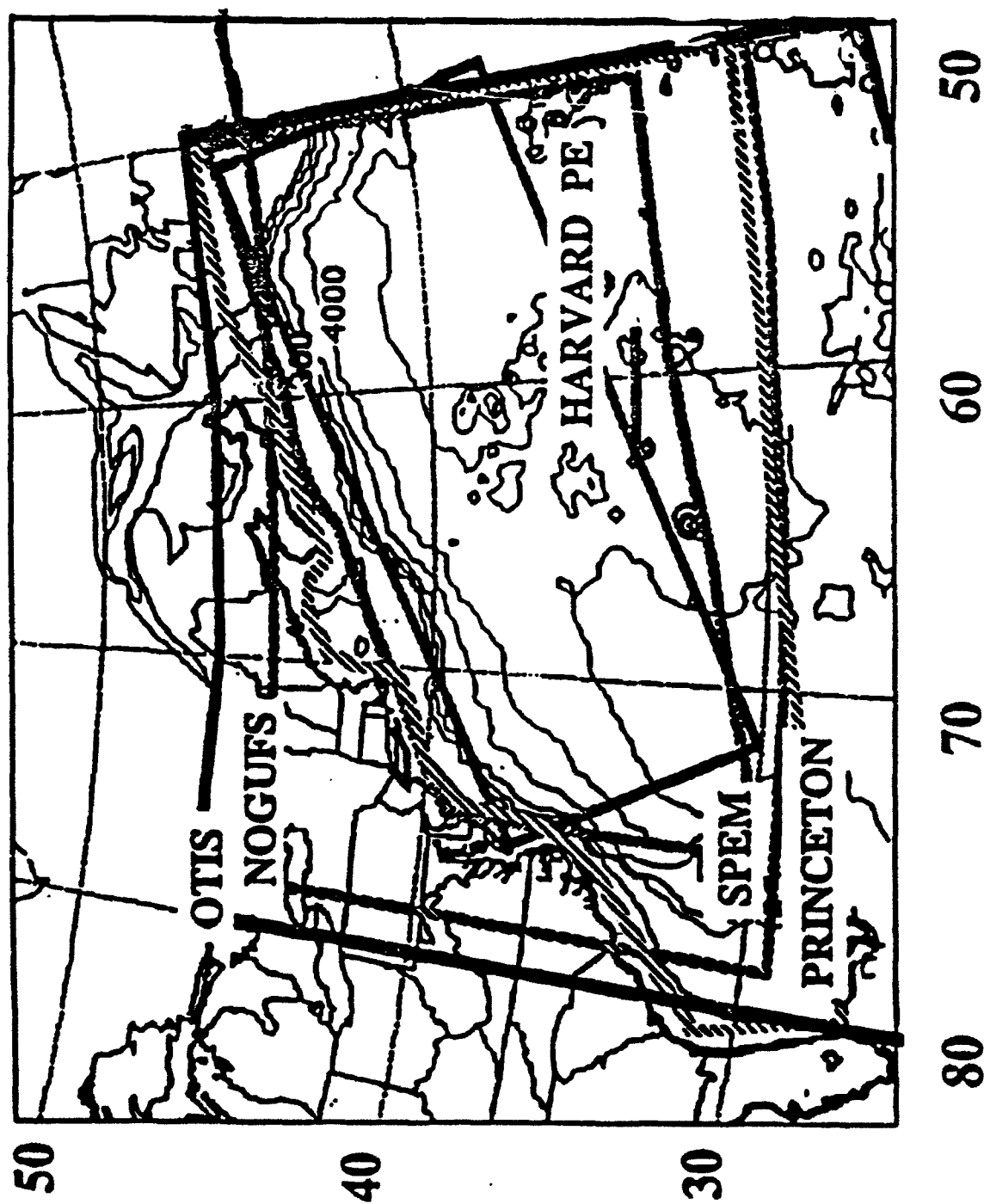


Figure 1. The DAMEE domain of studies. The OTIS Gulf Stream region contains participating model domains.

II. DAMEE Cases

The philosophy and the criteria for selecting DAMEE cases evolved from Phase 0 to Phase III. At the beginning of DAMEE (January 1991), INO sponsored a working meeting between Scott Glenn (who was at Harvard during the original case development), Dick Crout (who worked for NRL), and Louise Perkins to prepare an agreeable set of Gulf Stream analyses based on two (originally) slightly-different versions of verification analyses for the May 1988, May 1987, and July 1987 cases. The processes and results are described in Glenn, Crout, and Perkins (1991). Those cases were used in the Phase 0 experiment. The criteria were good AVHRR image coverage, REX AXBT underflights of GEOSAT, and the availability of GEOSAT altimetry for cross check. The philosophy was to provide analyses of an interesting Gulf Stream evolution at one-week intervals.

The feedback from those analyses from the participating groups, after the Phase 0 forecast experiment, were incorporated into the refinement of the analyses. Since the goal of Phase I was to identify the effect of data assimilation on model forecast, the same cases used for Phase 0 were used for Phase I.

In order to evaluate the capability to perform an extended forecast of a model with the aid of data assimilation, a one-month case was proposed. Based on the experience of the two previous Phases, the participants agreed with Scott Glenn that it was not necessarily the best choice to force the analyses to be at one-week intervals. Therefore, the central days of analyses float to the best available observations. This one-month case consisted of a series of analyses from 30 May to 4 July 1988. The interval between the two analyses varied from 5 to 9 days.

Originally, a second one-month case was proposed for the Phase III experiment. After careful evaluations by Scott Glenn and the attendees to the Phase II information exchange meeting (June 1992 at Diamondhead, MS), the proposed August -- September 1988 case was dropped because of the uncertainty of the Gulf Stream path at several segments on several days due to lengthy cloud cover. In fact, both the 4 May -- 18 May 1988 analyses and the 30 May -- 4 July 1988 analyses were exceptionally good cases. Therefore, the DAMEE participants decided to experiment with a two-month case in Phase III. This two-month case was formed by combining those two cases with a bridging date on 25 May 1988. The

philosophy in this choice was to use the best available analyses for long-term forecast. This two-month case also provided DAMEE experimenters a chance to investigate whether the model and data assimilation combination extended the forecast capability beyond one month.

The case selection for Phase II was meant to take advantage of the good coverage of observations near the Gulf Stream during the SYNOP field program. The spatial domain of the SYNOP experiment and the DAMEE overlap each other. Thus, the data sets from the SYNOP that fell within the time period of the DAMEE Phase II case would be of great value to generate a comprehensive data set. The SYNOP data sets included observations from arrays of current meters and inverted echo sounders (IES), moored acoustic Doppler current profilers (ADCP), shipboard hydrography, conductivity-temperature-depth sensor (CTD), expendable bathythermographs (XBT), dropsondes (POGO), expendable current profilers (XCP), RAFOS floats, and IR imagery.

Three moored ADCPs near 37.5°N , 68.5°W were part of the SYNOP central array at sites H3, H4 and I2 (Johns and Zantopp, 1991). Measurements were taken from 10 June 1988 through August 1990. They provided an almost one-month continuous measurement of near-surface current for the width of the Gulf Stream for our DAMEE Phase II. RAFOS float data were collected from April 1988 to March 1990 (Anderson-Fontana and Rossby, 1991, also see Figure 59). Thus, it also provided Lagrangian velocity data for cases in DAMEE Phases II and III. Floats were seeded in the Gulf Stream axis and gave us the most important information about the Gulf Stream current.

Figures 2 through 4 illustrate the Gulf Stream Surface North Wall position for the six, one-week cases (Case 1a, 1b, 2a, 2b, 3a, and 3b). The six, one-week cases could also be used as three, two-week cases (Case 1a+1b, 2a+2b, and 3a+3b), so only three plots were made. The Gulf Stream Surface North Wall, as derived from AVHRR imagery data, is defined as the maximum temperature gradient on the north side of the stream except for shingles. The solid line is the initial path, the long dashed line is the one-week path, and the short dashed line is the final two-week path of the Surface North Wall. Circles, squares, and triangles denote the initial, one-week and final positions of rings, respectively.

Table 2 gives a list of analysis dates for the four Phases of DAMEE.

Table 2. DAMEE Case Study Dates

OTIS Initialized Forecast	OTIS Initialized Forecast with Data Assimilation			
	Phase 0	Phase I	Phase II	Phase III
(1a) 4-11 May 1988	4-11 May 1988	(4) 30 May --->	(5) 4 May --->	
(1b) 11-18 May 1988	11-18 May 1988	5 June --->	11 May --->	
(2a) 6-13 May 1987	6-13 May 1987	13 June --->	18 May --->	
(2b) 13-20 May 1987	13-20 May 1987	22 June --->	25 May --->	
(3a) 7-14 July 1987	7-14 July 1987	29 June --->	30 May --->	
(3b) 14-21 July 1987	14-21 July 1987	4 July 1988	5 June --->	
			13 June --->	
			22 June --->	
			29 June --->	
			4 July 1988	

Numbers in parentheses are case numbers.

Case 1a & 1b: May 4, 11, and 18, 1988

Figure 2 is an overlay of the Gulf Stream North Walls and rings for all three analyses to illustrate the time history of the May 1988 case. During these two weeks, a small wave-like meander near 69°W propagated downstream, a warm ring formed near 65°W, the cold lobe meander got close to pinchoff, the warm lobe meander near 62°W grew bigger, the small trough near 60°W propagated eastward, and the meander crest near 54°W underwent an apparent relaxation. The day-to-day evolution of this meander crest near 54°W is uncertain between 11 May and 18 May. The scenarios consistent with available data include: (1) simple relaxation of the meander crest to form a straight Gulf Stream, (2) formation of a new warm ring that merges with the old warm ring already located near 54°W, or (3) absorption of the old warm ring followed by formation of a new warm ring.

Case 2a & 2b: May 6, 13, and 20, 1987

For the May 1987 case (see Figure 3), the initial Gulf Stream on 6 May has a large meander trough near 68°W and a large meander crest near 57°W . By 13 May, these meanders formed a cold and a warm ring, respectively. The existing cold ring near 63°W propagated towards the Gulf Stream. Over the next week, the Gulf Stream interacted with the cold ring near 63°W , which was advected downstream and almost absorbed. The Gulf Stream also interacted with the newly-formed warm ring near 58°W .

Case 3a & 3b: July 7, 14, and 21, 1987

At the beginning of the July 1987 case (see Figure 4), two large meander troughs shown at 61°W and 58°W , and a large meander crest appeared near 52°W . By 14 July, the western meander trough narrowed considerably, and the eastern meander trough formed a cold ring. The large meander crest formed a warm ring that remained close enough to the Gulf Stream to continue interacting. The Gulf Stream interacted with the warm ring near 62°W and advected it downstream. By 21 July, the western trough formed a cold ring near 59°W , which was so close to the cold ring formed during the previous week that the two rings interacted and apparently merged. There was evidence of only one large ring in this region after this event.

Case 4: 30 May -- 4 July 1988

Gulf Stream meander:

DAMEE Phase II had a one-month case to test the forecast capability of the model-data assimilation combination. The series of events represented by the Gulf Stream path and rings are illustrated in Figure 5. On 30 May, the beginning of the case, the Gulf Stream had a few shallow troughs and weak crests. The trough at 66.5°W moved steadily eastward while decreasing its amplitude. The shallow trough at 62°W , on the contrary, developed into a deep trough at 61°W on 22 June. The location of the developed trough was right above the New England Seamount (see Figure 1). After 22 June, the axis of the trough tilted along the Seamount orientation. The tilting may also have been caused by the Gulf Stream interaction with the pre-existent cold ring at 60°W . By 4 July, the deep trough formed a cold ring, and a huge ridge existed over the Seamount area.

Data Assimilation and Model Evaluation Experiments

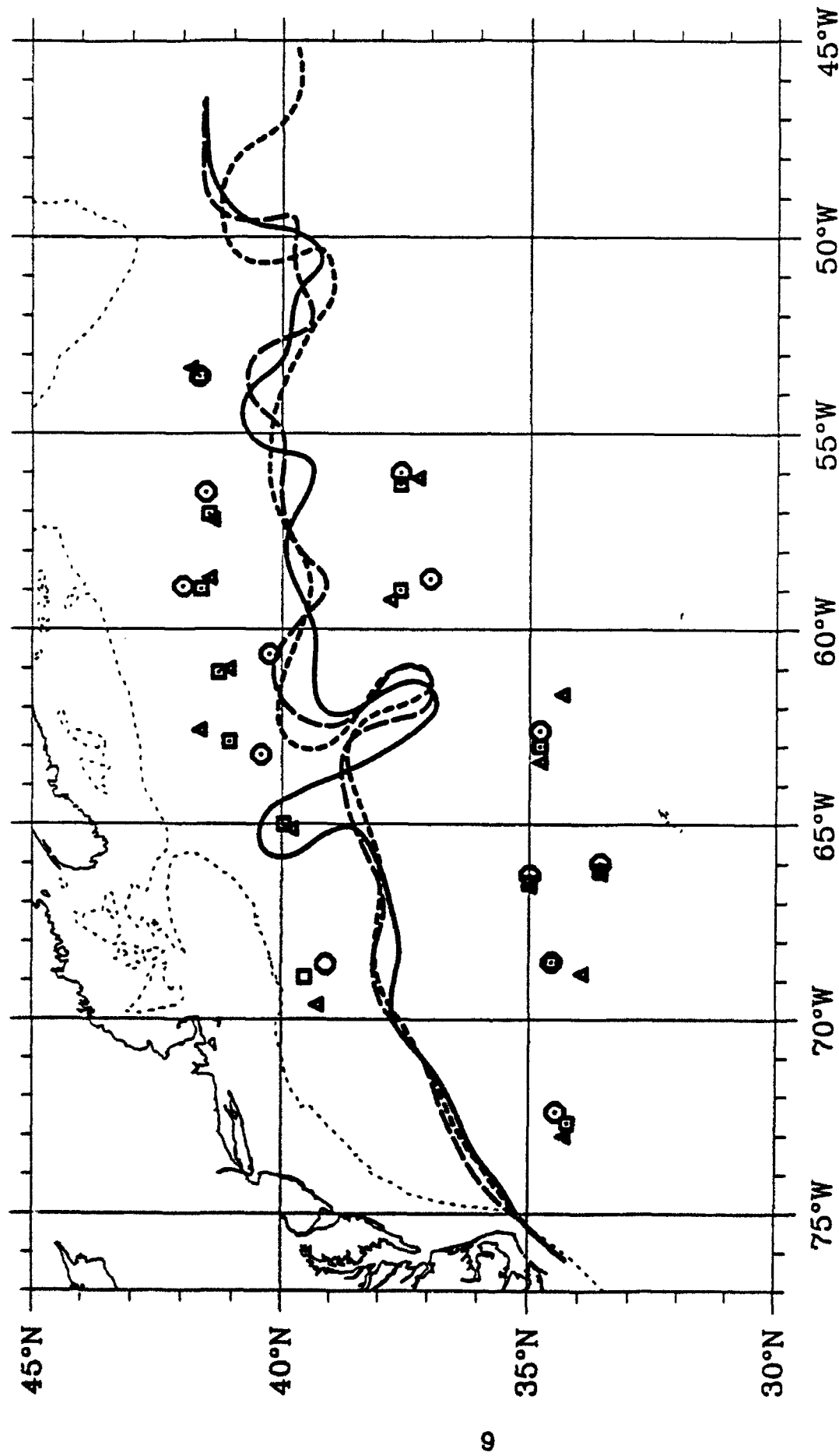


Figure 2. Time series of Gulf Stream North Wall and rings: 4-18 May 1988. The solid line is the initial path of Surface North Wall, the long dashed line is the one-week path, and the short dashed line is the final two-week path. Circles, squares, and triangles denote the initial, one-week, and final positions of rings, respectively. (Courtesy of Scott Glenn, Rutgers University).

Data Assimilation and Model Evaluation Experiments

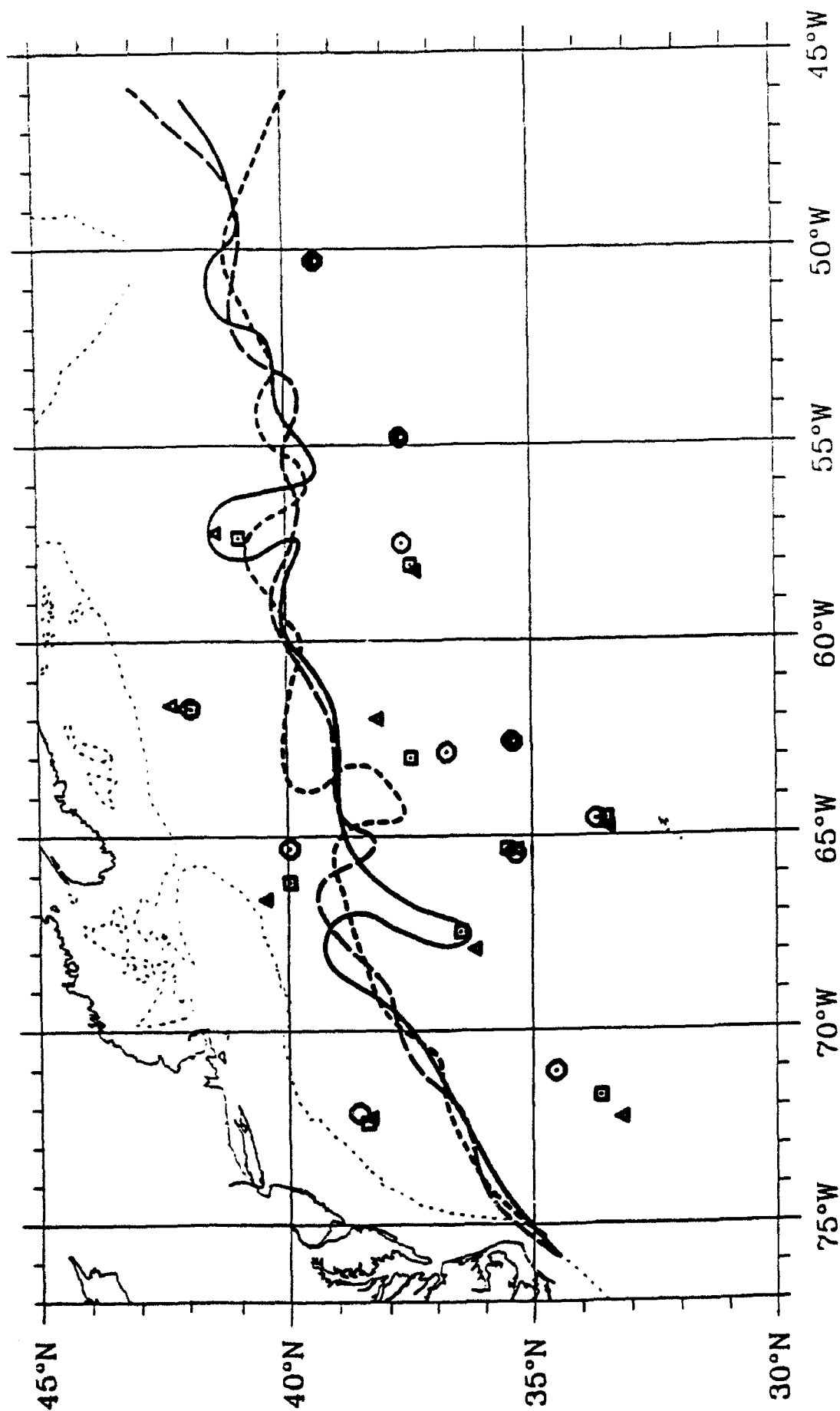


Figure 3. Time series of Gulf Stream North Wall and rings: 6-20 May 1987. (Same symbols as Figure 2)(Courtesy of Scott Glenn, Rutgers University).

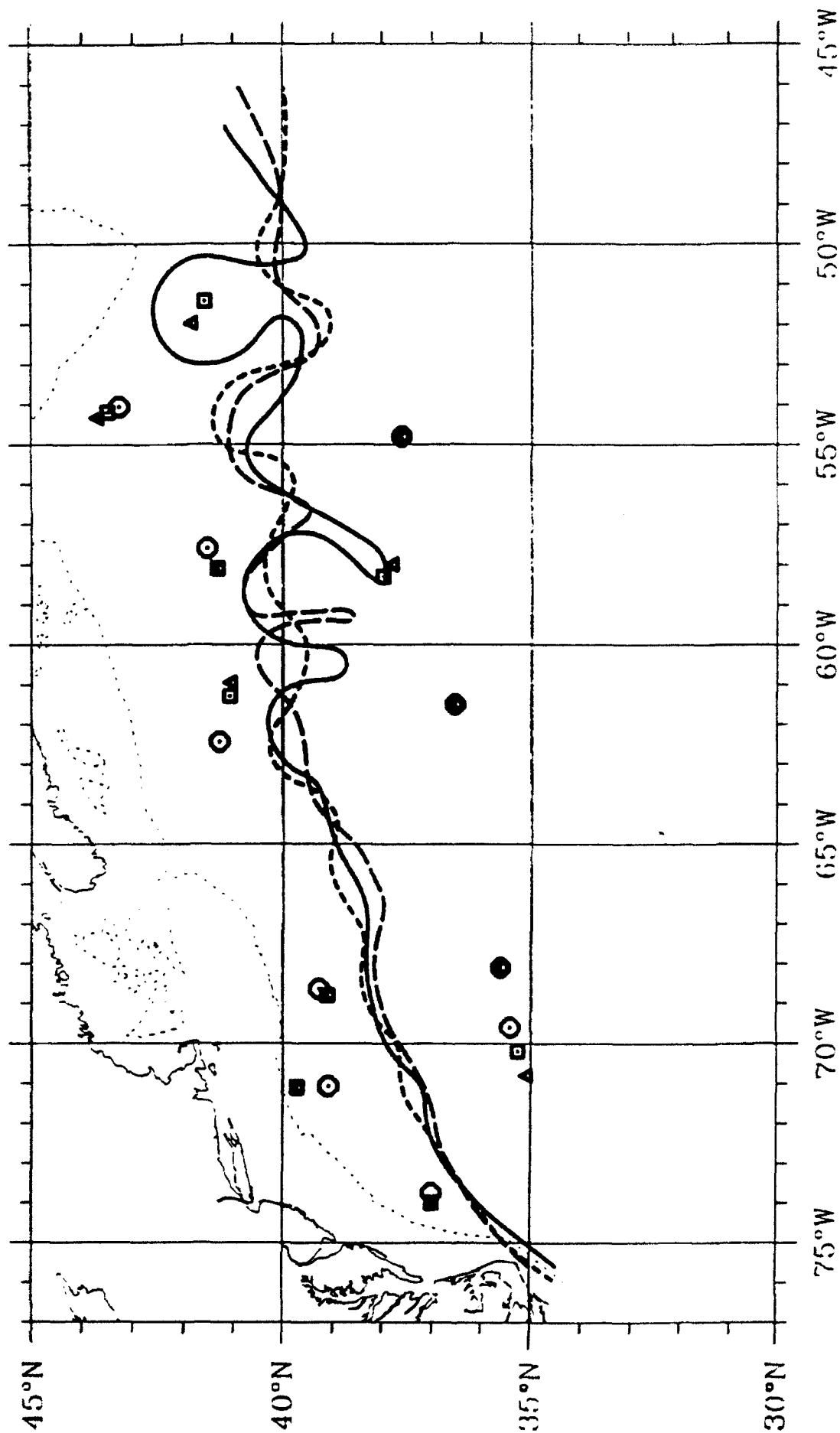


Figure 4. Time series of Gulf Stream Surface North Wall and rings: 7-21 July 1987.
(Same symbols as Figure 2)(Courtesy of Scott Glenn, Rutgers University).

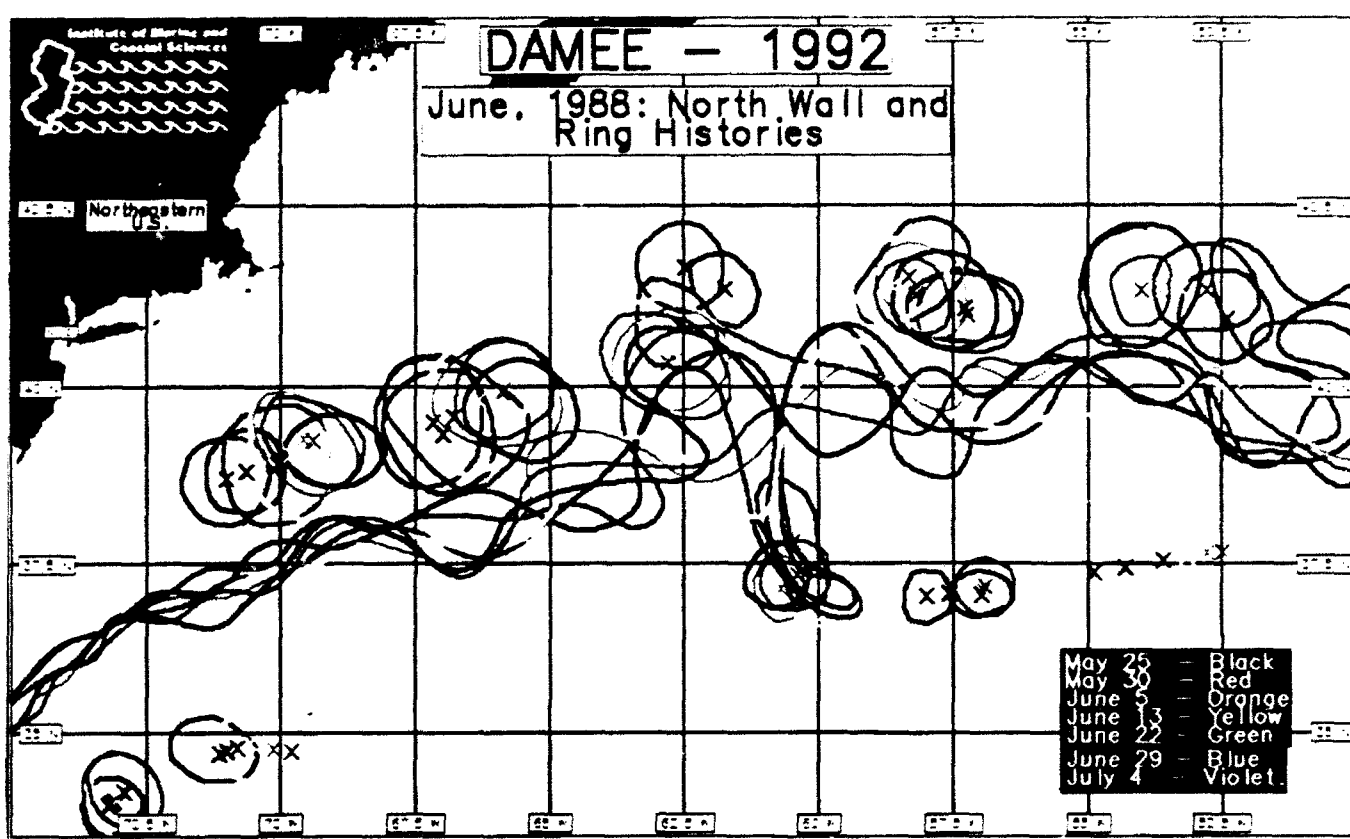


Figure 5. Composite analysis of Surface North Wall and ring history: 30 May - 4 July 1988.

The trough on the lee (at 58°W) of New England Seamount had moderate development between 30 May and 22 June. It had been locked into the same longitude, while the immediate upstream crest grew. The growth of the crest may have been associated with the warm ring near 58.5°W .

The two short waves at 72°W and 70°W on 30 May quickly disappeared before 13 June, but the short wave at 53.5°W on 30 May had a strange life. By 13 June, it eroded part of the crest immediately downstream. On 22 June, it dug out a moderate trough at 51°W , and the ridge downstream evolved into an appendix shape. At the end of the period, the crest extended northwestward to absorb the warm ring at 53°W , 41.5°N .

Rings and ring-stream interaction:

There were five warm rings and five cold rings at the beginning of the case. Let's label the warm rings as W1 through W5, from west to east, and the cold rings as C1 through C5, from west to east.

W1 and W2 moved steadily toward west-south-west throughout the whole period and did not interact with the Gulf Stream. W3 was a very interesting ring; it influenced the growth of the crest which was moving from 65°W to 62°W . At the beginning, W5 moved westward, approaching the upcoming and amplifying crest. Then, it was pushed (or steered) eastward. By 4 July, it resumed the west-south-west motion. W4 was weaker than W3. It also began with a westward drifting. After 22 June, it encountered the same fate as W3, being pushed back; but it happened a bit later until the crest and W4 were close enough. W5 had been drifting eastward since the beginning. It was absorbed into the Gulf Stream crest around 51°W and formed a meander.

C1 had been stagnant throughout the whole period. C2 moved slowly and steadily toward the southwest. C3 had a "sob" story; it had been "sucked" into the deep trough at 61°W when it was wandering above the New England Seamount between 13 June and 29 June. By 4 July, it was discarded on top of the Seamount at 60.5°W , 37.7°N . Then it regained its strength. C4 and C5 were not much affected by the Gulf Stream. C4 had a steady westward motion all the time. It was close to the deep trough at 60°W , yet stayed as an entity. C5 took a steady southward motion all the time at a relatively fast pace.

Major events:

Major events during this one-month case were: (1) the dramatic deepening of the trough between 62°W and 60°W and the break-off of the trough into a cold ring, (2) the growth of the crests immediately upstream and downstream of the deep trough, (3) the interaction between W3 and the crest, (4) the absorption of C3 by the deep trough, and (5) the absorption of W5 by the crest at 51°W . The first four events occur geographically around the New England Seamount.

Case 5: 4 May -- 4 July 1988

This two-month case was completed by combining Case 1, Case 4 and a bridging date on 25 May 1988. During the first two weeks (4 May -- 18 May), a segment of Gulf Stream meander consisting of a large crest and a deep trough near New England Seamount evolved into a new warm ring and a new cold ring. By 25 May, the growing warm lobe near 62.5°W absorbed the warm ring to the north; and the newly-formed cold ring merged with a nearby cold ring to the east. By 30 May, the enlarged warm lobe at 62.5°W pinched off to form a warm ring. So, the Gulf Stream returned to a more relaxed jet, flanked by six warm rings and five cold rings. The evolution of the Gulf Stream during the next month was described earlier. It was another cycle of meandering and ring-stream interaction. The Gulf Stream Surface North Wall and rings are shown in the figures of Section III.

III. DAMEE Data Preparation

To properly initialize the Primitive Equation (PE) models and provide boundary conditions, a high-quality analysis of some of the primitive equation variables has to be carefully prepared. Ideally, we wish to obtain a high density of observations of all primitive equation variables (temperature, salinity, dynamic height, and horizontal velocity). In reality, there are only sparse observations of temperature, salinity and horizontal velocity from XBT, mooring, IES, etc. The most abundant datum is the Multi-Channel Sea Surface Temperature (MCSST) which is derived from the satellite AVHRR remote sensing. The next one is the satellite altimetry data. However, both kinds of data are 2-D fields; they are not enough to properly initialize PE models.

The concept of "feature model" (Bennett, Carnes, Phoebus, and Reidlinger, 1988) and the Optimum Interpolation (OI) technique make possible the preparation of a high-density 3-D data set for model initialization and verification. The INO chose OTIS, developed by the FNOC, to prepare the DAMEE data sets because it utilizes those two approaches in blending available information; it also provides a 3-D temperature and salinity data set, 2-D dynamic height field, and more. OTIS is a still-evolving operational ocean interpolation system (see Clancy, Phoebus, Pollack and Cummings, 1990; Cummings and Ignaszewski, 1991). A more detailed description of OTIS is given in the following subsection.

A. OTIS package

Version 3.0 of the OTIS is the most technically-advanced ocean thermal structure analysis model now operational at the Fleet Numerical Oceanography Center (FNOC). It has been tested by scientists from FNOC, the Naval Eastern Oceanography Center (NEOC), the Naval Postgraduate School (NPS) and the NRL.

OTIS 3.0, a very sophisticated model, implements the OI data assimilation technique to assimilate real-time ship, bathy, buoy, satellite MCSST and "synthetic" data into a complete 3-D surface-to-5,000 m representation of ocean thermal structure. Using empirical techniques, it also derives a full 3-D salinity representation, consistent with the analyzed temperature. Due to sparse subsurface data, OTIS 3.0 relies heavily on "synthetic" bathythermograph data to supplement the "real" observations. The OTIS produces the synthetic data internally from (1) an

Empirical Orthogonal Function (EOF) representation of individual water masses, as analysis of all available sea surface temperature (SST) data at synthetic data locations, (2) "Ocean feature models" describing the transitional structure between water masses, and (3) the information defining the surface positions and other characteristics of fronts and eddies contained in the Naval Oceanographic Office (NAVOCEANO) ocean bogus. The synthetic data are voluminous and concentrated in the vicinity of the mesoscale ocean front and eddy features delineated in the NAVOCEANO bogus, which is based primarily on a subjective interpretation of satellite imagery. The synthetic data provides far more information on subsurface thermal structure than would otherwise be available.

Sophisticated and rigorous quality control on all incoming observations are performed by OTIS 3.0 to ensure that spurious reports are omitted and good reports are retained in the analysis. Anomalies between the accepted temperature observations and the Master Generalized Digital Environmental Model (GDEM) temperature climatology, interpolated in time to the day of the observation, are calculated and stored in a running-time window for up to 60 days. A new and complete set of synthetic temperature anomalies are calculated each day from the latest NAVOCEANO bogus.

The OI technique combines the observed and synthetic temperature anomalies with (into) a first-guess field provided by Master GDEM to produce the final analysis. The technique assigns the weighting of each piece of data (both real and synthetic) received in the final analysis based on the time-space distribution of the data, their assumed error variance and standard OI statistical parameters describing the nature of the thermal variability in the analysis region. The resulting product gives an accurate 3-D representation of the temperature and salinity structure, including a realistic depiction of the fronts and eddies identified and tracked in the NAVOCEANO bogus.

Figure 6 shows the temperature field at a 100 m depth from the OTIS 3.0 analysis for the Gulf Stream Region at 00Z 7 Dec. 1990. The Gulf Stream Front, the Shelf-Slope Front and several cold and warm eddies are prominent. Figure 7 is an example of vertical temperature cross-section from the OTIS 3.0 analysis at 00Z 14 Sept. 1990.

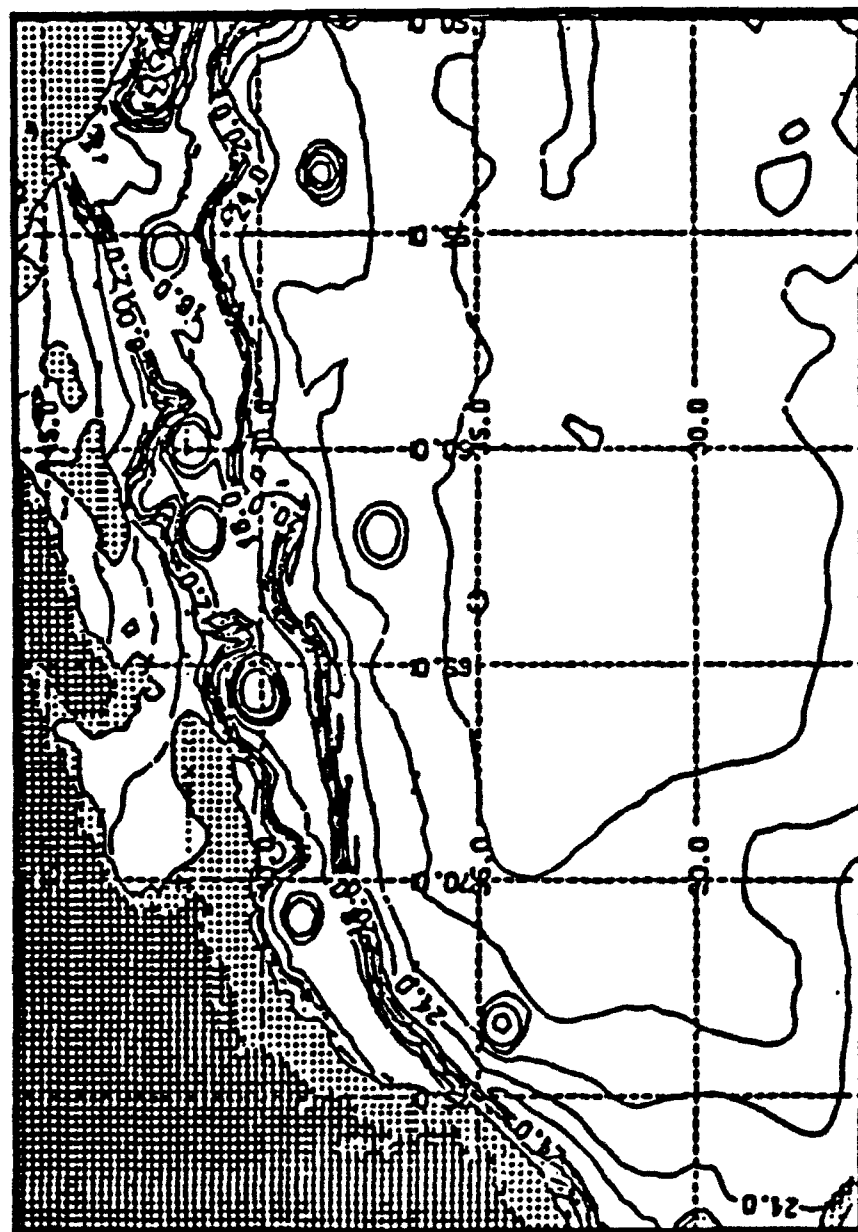


Figure 6. Temperature at 100 m depth from the OTIS 3.0 analysis for the Gulf Stream region at 00Z 7 Dec. 1990. The contour interval is 1° Kelvin. (Courtesy of James Cummings, FNOC).

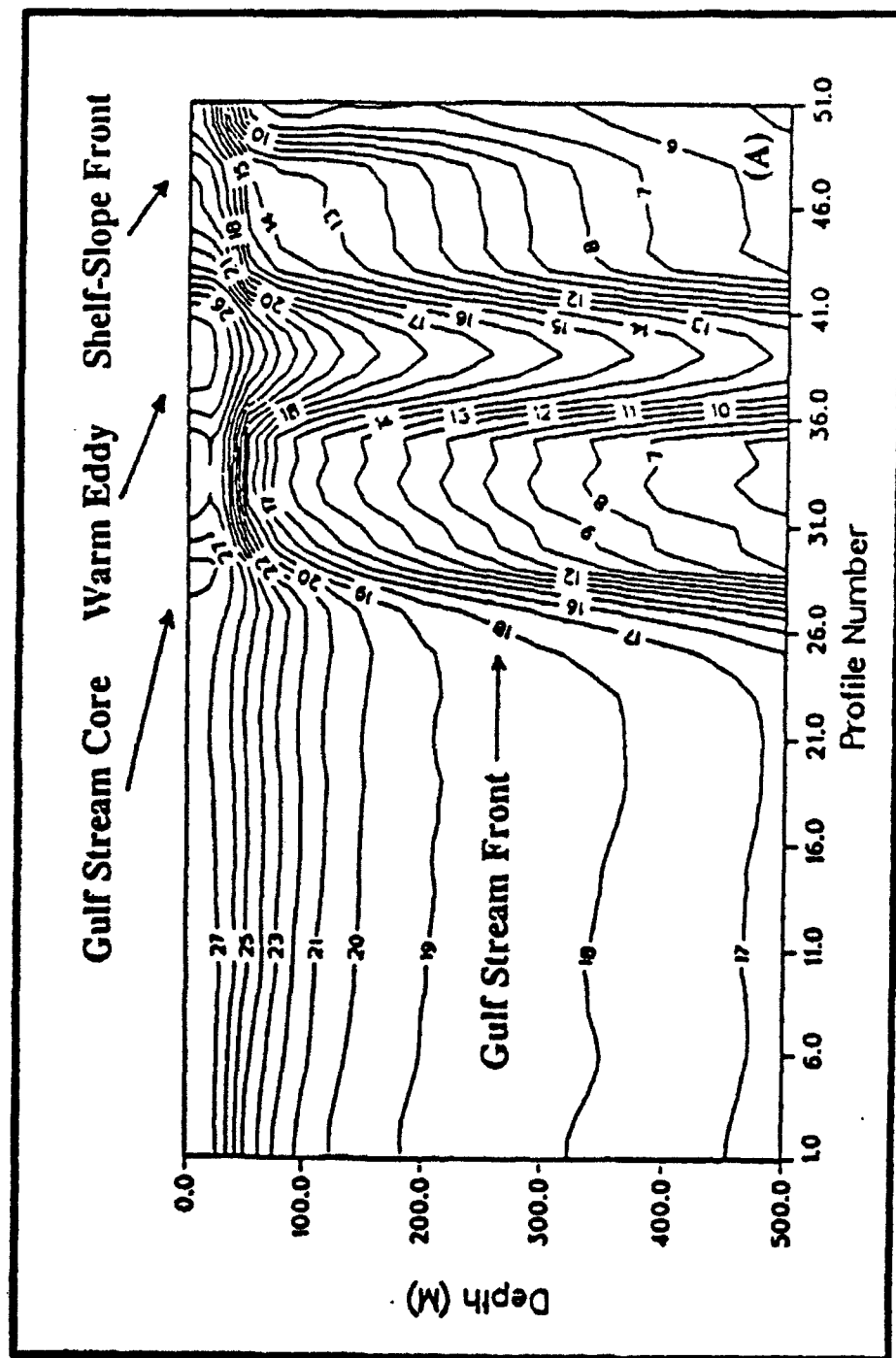


Figure 7. Vertical temperature cross section from the OTIS 3.0 analysis from 00Z 14 Sept. 1990 along a track which extends northward from near Bermuda across the Gulf Stream through a warm eddy and across the Shelf-Slope Front. The contour interval is 1° Kelvin. (Courtesy of Mike Carnes, NRL).

OTIS 3.0 consists of seven main programs and approximately 100 subroutines. The following is a summary of the OTIS package:

(a) Input data:

- Generalized Digital Environmental Model (GDEM) climatology
- NAVOCEANO bogus information
- Satellite derived sea surface temperature (MCSST)
- Bathythermograph (XBT)
- Ships' observations
- Fixed and drifting buoys
- Coastal marine stations

(b) Output data:

- 3-D temperature fields
- 3-D temperature error fields
- 3-D temperature anomaly fields
- 3-D salinity fields
- 2-D dynamic height field

(c) Regional areas:

- Gulf Stream Region (operational)
- Northern Kuroshio Region (operational)
- Greenland-Iceland-Norwegian Sea area (operational)
- Caribbean - Gulf of Mexico
- Mediterranean Sea
- Labrador Sea
- Mid-Atlantic
- Sea of Japan
- Mid-Pacific
- Eastern Pacific
- Western Tropical Pacific
- Indian Ocean

(d) Analysis procedure:

1. Observations are classified according to their water mass of origin by a multivariate Bayesian analysis.
 - Water mass class parameters (mean, variance, probability) are determined from historical data.
2. Satellite and buoy data are reduced by spatially averaging the observation anomaly and location within a correlation length scale to form super observations.

3. Mesoscale eddies are identified from bogus maps (maps which depict the location of mesoscale fronts based on IR imagery, altimetry and XBTs).
4. Eddy fringe locations are fit, in a least-squares sense, to an ellipse with output in the form of eddy center, major and minor axis lengths, and major-axis orientation.
5. Bogus data are incorporated into feature models to generate synthetic observations at an adequate resolution:
 - Given a feature location and frontal path, compute the orthogonal distance to the front and the orthogonal crossing point on the frontal path.
 - Compute expected property difference (temperature or salinity) across the front using bilinear interpolation of water mass-based temperature and salinity climatology.
 - Interpolate the property difference across the front to the feature location forming the frontal gradient by solving for the width and slope of the front.
 - Integrate the gradient current relationship to give an estimate of absolute dynamic topography at any arbitrary position within the eddy ellipse.
 - Thermal and salinity structure at the feature locations is estimated using the first two EOFs which relate surface dynamic height and sea surface temperature (SST).
6. The resultant synthetic profiles from the front and eddy models are referenced to the GDEM first guess climatology and added to the observational data base for the data assimilation.
7. The observational data base is quality controlled prior to the assimilation.

8. Variability is parameterized in terms of space/time covariance functions.
9. Gaussian covariance models are fit to the data using least squares procedures.
10. The influence radius for the distance-weighted scheme is specified by the e-folding water mass correlation length scales derived by a bin-average approach.
11. Perform assimilation and verification statistics.

B. Data Input to OTIS

Data input to OTIS include bogus information, MCSST, XBT, and GDEM. Bogus is a subjective analysis of the Gulf Stream system including the Surface North Wall path, warm/cold ring center, size, orientation and swirl velocity, etc. It is the most complicated and important information required by the OTIS package. Detailed descriptions about the properties of OTIS input data are given in the following subsections.

Data used by OTIS to generate the gridded analysis are prepared from several observational data. These include: (1) MCSST fields obtained from the NASA Ocean Data System (NODS) at the Jet Propulsion Laboratory, (2) MCSST Region 6 and 7 obtained from NOAA/NESDIS National Climatic Data Center (NCDC), (3) XBT data from NAVOCEANO and AXBT from NRL (then NOARL) REX field project and Harvard Gulf Stream Forecasting project, (4) NAVOCEANO GDEM-like coefficients set, (5) NAVOCEANO Gulf Stream IR imagery, (6) GEOSAT altimetry provided by APL at Johns Hopkins University, (7) Ocean Frontal Analysis provided by NEOC, and (8) Bogus information prepared jointly by DAMEE participants (Scott Glenn, Louise Perkins, Aaron Lai, and Wen Qian), NRL employees.

1. Merging and quality control of observed data

Because there are only sparse observations, merging of observed data is necessary in order to prepare an analysis for the required domain. However, it takes extra effort to prepare a reliable analysis of data for OTIS from those spatially and temporally inhomogeneous observations. Different sources and different types of information also make the judgment of quality difficult.

The preparation of OTIS input data had gone through several iterative stages. The first stage was to prepare GDEM-like climatology, MCSST data, XBT casts and bogus maps. The bogus maps for Cases 1a, 1b, 2a, 2b, 3a, and 3b were prepared from the CIMREP data base. Details of the process are given in Glenn, Crout and Perkins (1991). Bogus maps prepared in this stage contained warm and cold ring centers, sizes, temperatures and Gulf Stream Surface North Wall to the north of Cape Hatteras and to the west of 50°W only. Before OTIS was run, a mean Gulf Stream Surface North Wall from 27°N to Cape Hatteras (see Auer (1987)) was added. The OTIS outputs were used in the Phase 0 experiment.

The data in this stage had three problems. First, models initialized with this data tended to forecast the formation of a ring too late or too unrealistic in ring size. Second, the temperature and salinity fields had a contrast that was too strong across the Gulf Stream as well as a lack of mesoscale texture. Third, there appeared to be a shift of the Surface North Wall by OTIS.

The second stage of data preparation, basically, was to correct the problems shown in the results from the first stage. It included: (1) the comparison of bogus maps prepared in house with other analyses by NRL and modification of some segments of the Gulf Stream Surface North Wall, (2) the checking of subroutines used in the temporal cubic spline interpolation of MCSST data and correcting a mistake, (3) the communicating with FNOC scientist (Jim Cummings) and applying the correct frontal structure to the Gulf Stream and Slope Front. Because part of the FLEXCAST model domain extended to 47°W, the OTIS domain became 82°W to 47°W in the west-east direction. The OTIS outputs based on those modified bogus maps gave more realistic fields. This data set was used in the Phase I experiment.

The next stage was to compare the bogus maps with other independent analyses and to merge them into a complete analysis of the Gulf Stream system. The independent analyses used in this stage included: (1) the Ocean Frontal Analysis charts prepared by the NEOF (see Figures 8 and 9), and (2) the Gulf Stream Surface North Wall analysis prepared by the University of Rhode Island (see Figures 10 and 11). In this stage, the mean Gulf Stream Surface North Wall between 27°N and Cape Hatteras, used in the first stage, was replaced with the analysis shown on the NOAA/NOS Oceanographic Analysis chart for the date. The Gulf Stream Surface North Wall analysis was also extended to 45°W. This provided

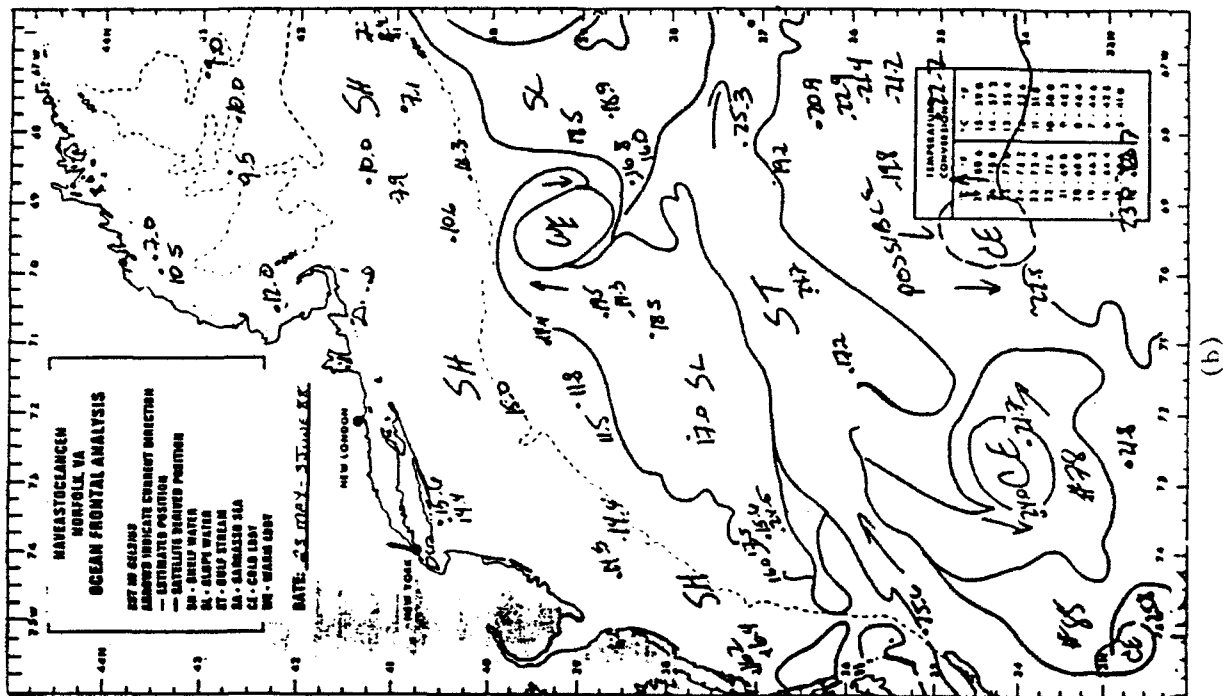
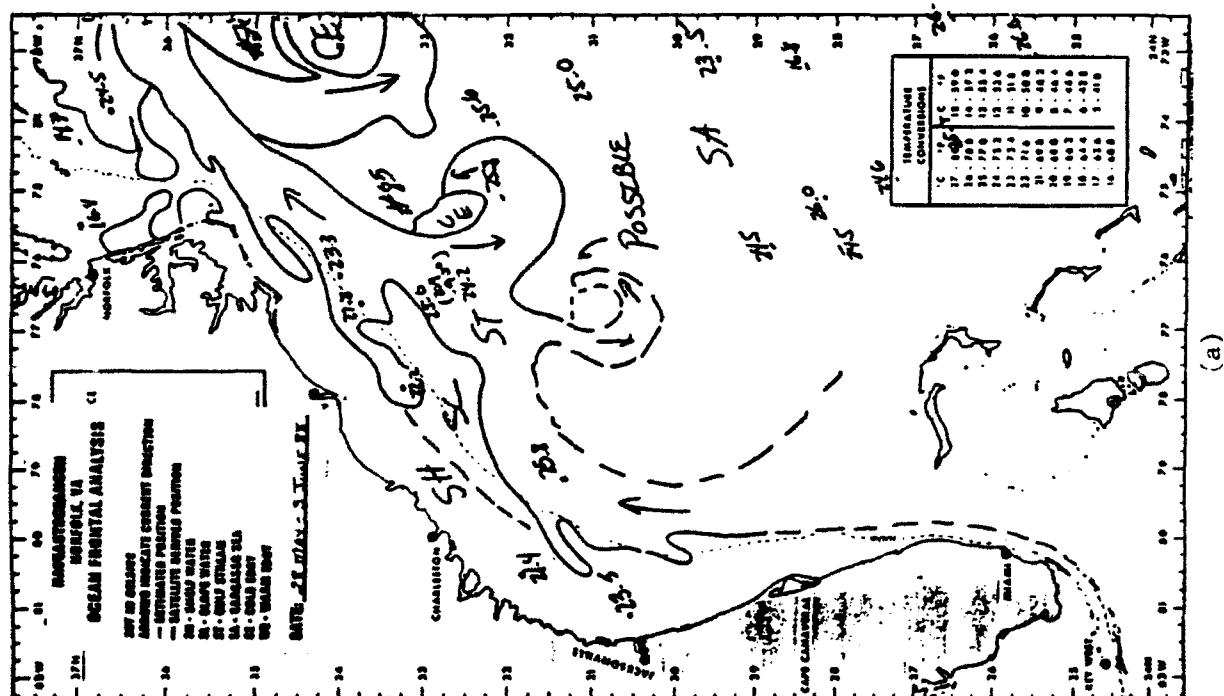
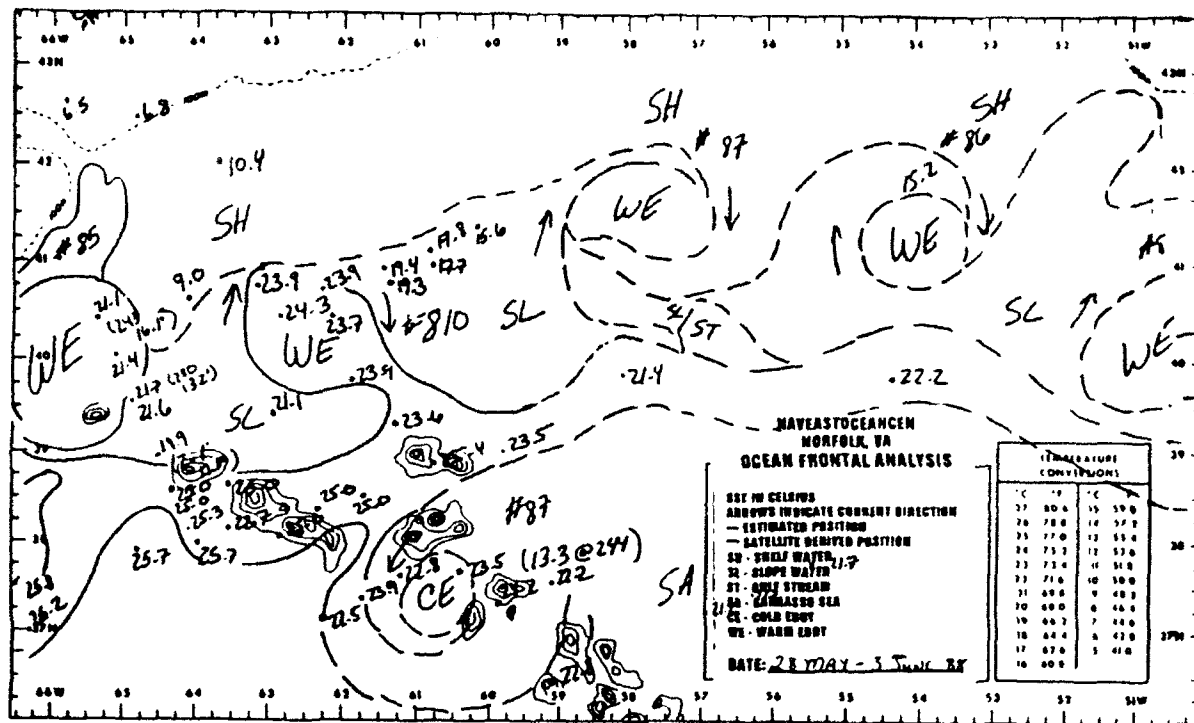
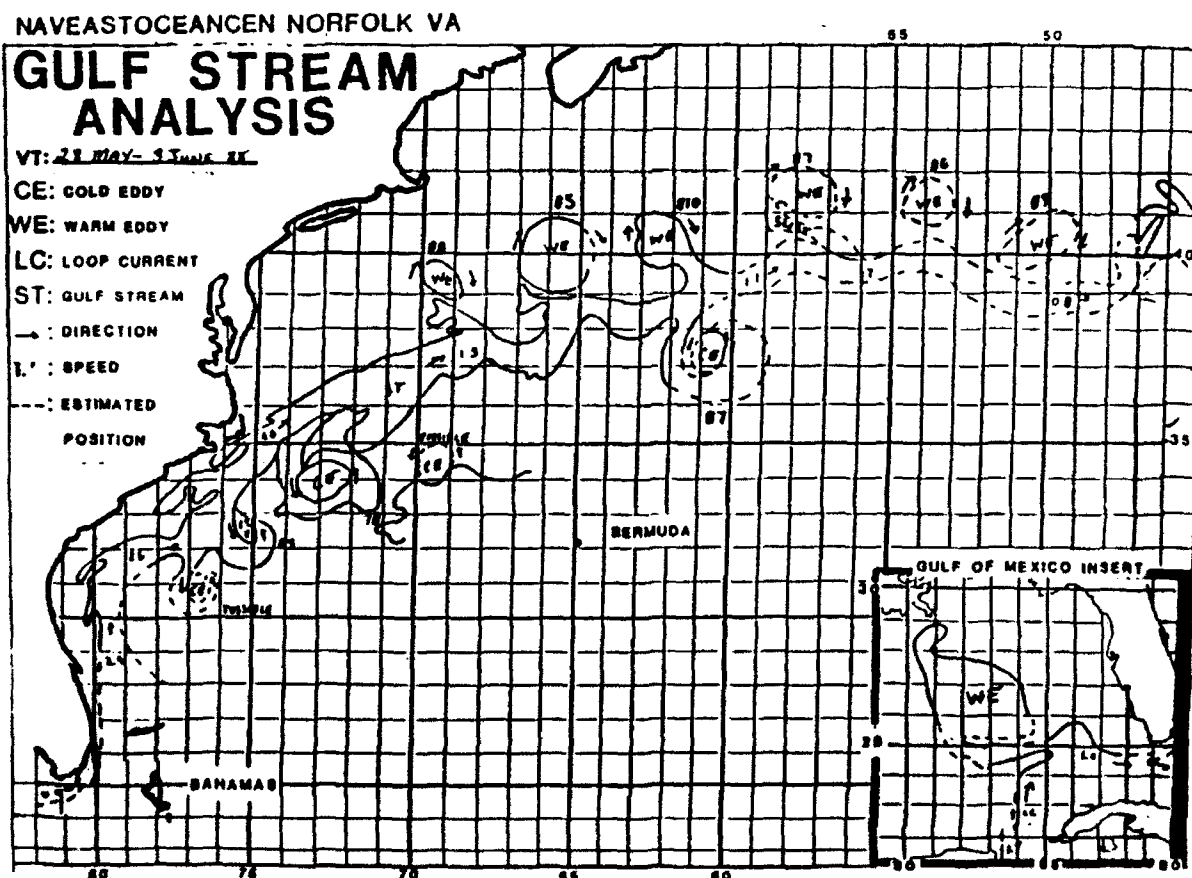


Figure 8. Ocean frontal analysis chart for 28 May - 3 June 1988, (a) lower Gulf Stream section, (b) east of Cape Hatteras section.



(a)



(b)

Figure 9. Ocean frontal analysis chart for 28 May - 3 June 1988, (a) mid-Atlantic section, (b) Gulf Stream analysis.

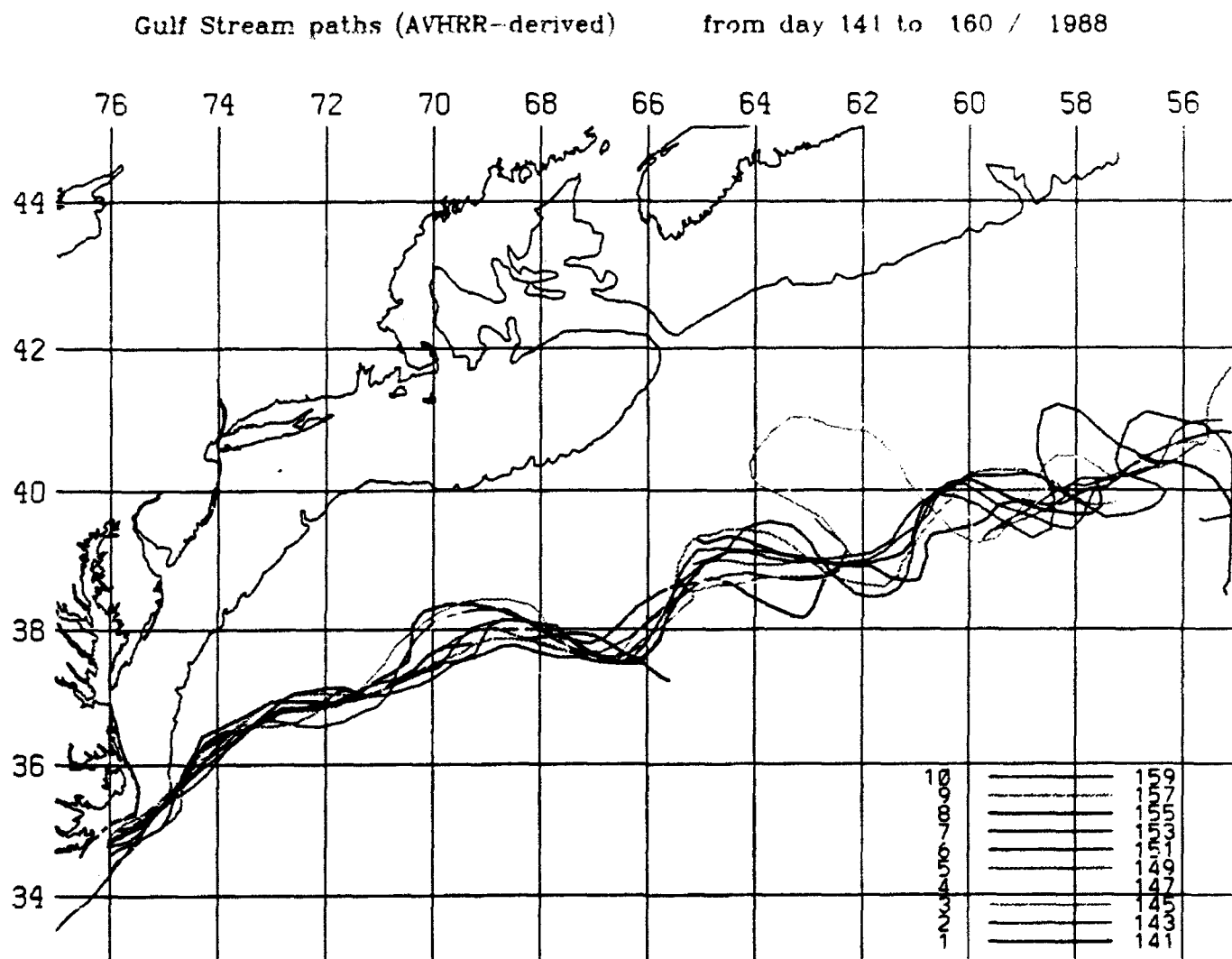


Figure 10. Time series of Gulf Stream Surface North Wall from day 141 to 160, 1988.

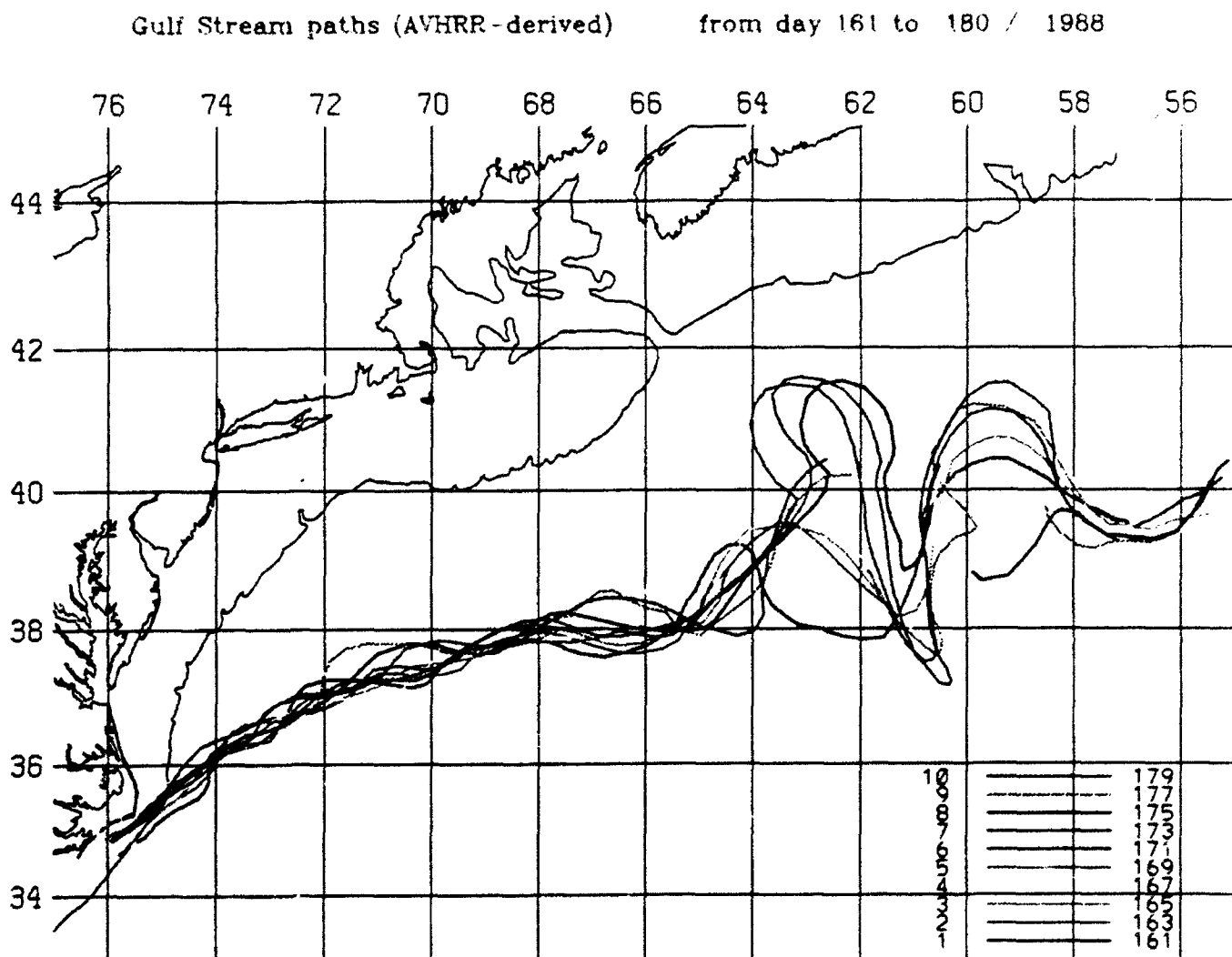


Figure 11. Time series of Gulf Stream Surface North Wall from day 161 to 180, 1988.

better temperature and salinity fields near the eastern boundary (at 47°W). The warm and cold rings interacting with the Gulf Stream were checked carefully to ascertain their identities. Some elongated crests and troughs were checked to make sure they were not a misinterpretation of warm or cold rings near the Gulf Stream. The central temperature and size of rings were also checked to attain continuity and be comparable to the AVHRR analysis. The OTIS outputs based on bogus maps of this stage demonstrated very good spatial and temporal continuity. This data set included all cases for Phase I, Phase II and Phase III.

The last stage of preparation was to check the OTIS output fields with the input XBT data. It resulted in a finding of incorrect temperature unit used in some AXBTs provided by NOARL. Therefore, OTIS fields were regenerated and plotted.

2. Bogus map

The most important and sensitive data set among all inputs to OTIS was the bogus information. Bogus is a subjective interpretation of the Gulf Stream system. Data used in obtaining this analysis, however, are objectively analyzed quantitative information, e.g., AVHRR field, GEOSAT altimetry data, XBT casts, etc. The information contained in the bogus map were (1) Gulf Stream Surface North Wall, and (2) warm and cold ring locations, sizes, central temperatures, ages, swirl velocities, etc.

The Surface North Wall is defined as the maximum temperature gradient on the north side of the feature identified as the Gulf Stream observed in the satellite AVHRR imagery. One had to first identify the Gulf Stream before finding the maximum gradient of temperature, because sometimes the temperature gradient between the shingles and slope water is stronger than that between the Gulf Stream and shingles. The Surface North Wall was also obtained from the GEOSAT data. It is defined as the location at which the sea surface height (SSH) begins to level off after crossing the Gulf Stream. The estimated errors of the Surface North Wall from these two data types are 15 km/day and 14 km, respectively.

Bogus maps for Cases 1, 2, and 3 were derived from CIMREP case analyses. The original reason for preparing the CIMREP cases was for a validation study of the 1987 version of the Harvard quasi-geostrophic model. This model requires, as input, the location of the Gulf Stream velocity axis rather than the Surface North Wall. Therefore, in order to

obtain the Surface North Wall, the original 25 km offset was added back to the north of the digitized CIMREP Gulf Stream Axis.

The data used to prepare the CIMREP cases included NOARL IR imagery, the NOARL analysis of GEOSAT altimetry using a classified geoid, the REX along track AXBT flights, and the weekly Harvard AXBT survey flights. The archived FNOC and NODC AXBTs were also used in the final preparation of bogus maps of Cases 1, 2, and 3. Because some rings can remain unobserved in AVHRR imagery for weeks, the historical GEOSAT Ocean Application Program and the geoid provided by the Applied Physics Laboratory of Johns Hopkins University (see Glenn, Porter, and Robinson, 1991) were used to get historical interpretations of the warm and cold ring locations. Since relatively little data is available on the ring swirl velocities, the estimates were based largely on estimates of ring age. Although individual data sets can be patchy in regions, an aggregate data set may cover the entire domain. This approach was used in preparing the bogus maps for Cases 1, 2, and 3.

Figure 12 shows the smoothed Gulf Stream axis (heavy dashed line) and error bars (solid lines) for 4 May 1988. Figure 13 is an example bogus map showing the smoothed Gulf Stream axis (heavy dashed line), smoothed Surface North Wall (heavy solid line) and the ring locations for 4 May 1988. The distance between the Gulf Stream axis and Surface North Wall is 25 km.

The preparation of bogus maps for Cases 4 and 5 was independent from any earlier analysis. When bogus maps for CIMREP and Cases 1, 2, and 3 were being prepared, climatology was used to fill in data gaps in order to force the analyses to be at one-week intervals. It was a bad assumption in hindsight because that favored persistence during times of patchy data. So, for the one-month case (Case 4), days with very clear imagery were chosen as central days for composite analysis. In this analysis, a thresholding and patching technique, rather than the customary warmest pixel technique, was used to composite infrared images. The result was less smearing of features than warmest pixel composites. Images within ± 2 to 3 days of each central day were processed. First, pixels with temperatures below a specified threshold were assumed to be contaminated by clouds and were deleted from each image. The remaining pixels from each image were then patched together, one image at a time. The image-by-image patching process involves replacing pixels in the composite with the remaining pixels in each threshold image. The

Data Assimilation and Model Evaluation Experiments

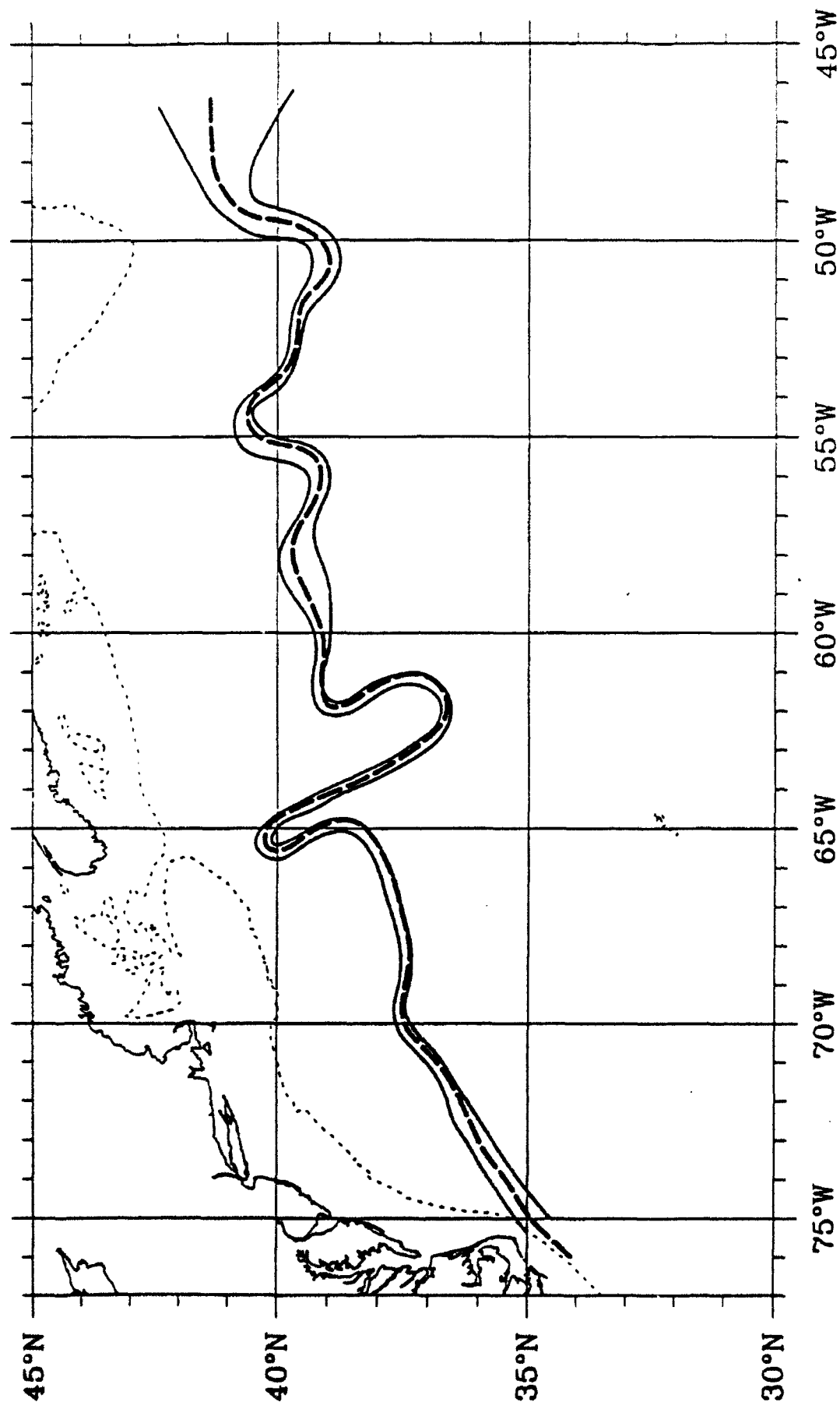


Figure 12. Gulf Stream axis (heavy dashed line) and error bars (solid lines) for 4 May 1988. (Courtesy of Scott Glenn, Rutgers University).

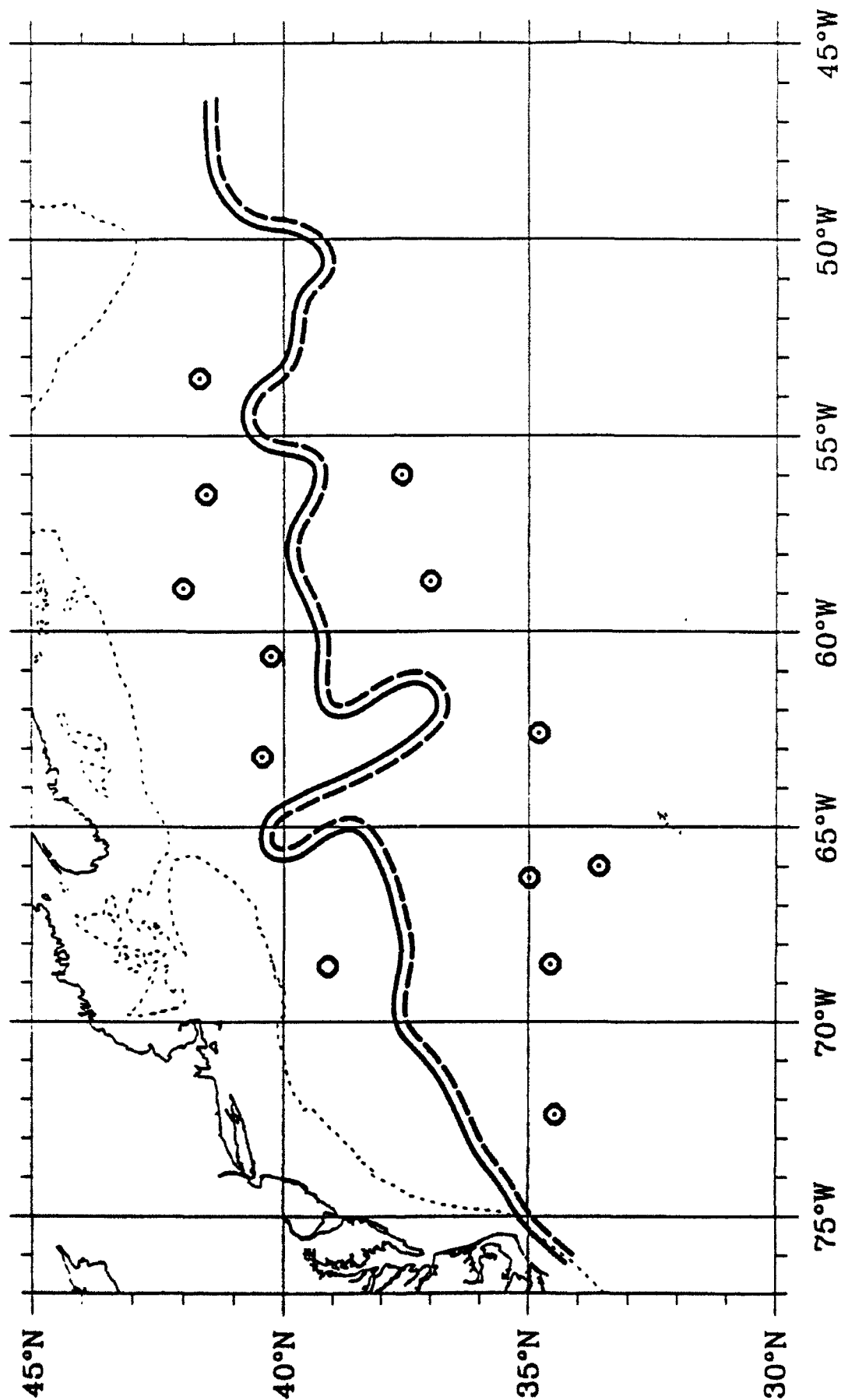


Figure 13. Gulf Stream axis (heavy dashed line), Surface North Wall (heavy solid line) and ring locations (circles) for 4 May 1988.

composite was patched together with the images furthest in time from the central day substituted first and the central day image substituted last.

Besides infrared imagery, GEOSAT dynamic topography and XBT/CTD temperature profiles from a variety of sources were used in analyzing the Gulf Stream Surface North Wall, the ring centers and the ring edge. For each ring, the time series of observed ring parameters (central location, size and strength) were interpolated to the central days. Figures 14-19 are composite satellite images, GEOSAT altimetry analyses, and bogus analyses for 30 May through 4 July 1988. The two-month case is a hybrid analysis of Case 1 and Case 4. The main thrust in preparation was to attain a consistency and continuity of the Gulf Stream system.

The complete set of bogus maps are shown in the lower-left panel of figures at the end of Subsection III.B. (see Figures 26 -- 41) The yellow represents the Surface North Wall. The vertical crosses represent the warm and cold rings. The size of the cross is proportional to the size of ring and the temperature at the center of ring is color coded.

3. MCSST

MCSST is the most abundant data among OTIS inputs. There are two different sources of MCSST analysis deriving from basically the same NOAA AVHRR digitized field. The NCDC source gives finer spatial resolution than that for NASA/JPL's. The NASA/JPL's data sets were used in preparing the MCSST data for OTIS because (1) it needed to merge NCDC data for two regions (Region 6 and Region 7) into one set and still did not cover the entire OTIS domain, (2) the NCDC data is a semi-weekly composite and is not specific in date. So, the MCSST data for OTIS was prepared from NASA/JPL's and the NCDC's was a counter-check.

NASA/JPL's MCSST data set has a resolution of approximately 0.175 degree in latitude and longitude. Every analysis is a weekly composite of the field. To obtain the MCSST for OTIS, data were first interpolated from NASA/JPL's grid into OTIS's grid using bilinear interpolation. Then, the weekly composite was interpolated in time to the date of each case using a cubic spline fit. Figure 20 shows the MCSST for 6 May 1987. The color bar at the bottom of the figure gives the color-coded temperature range. The Gulf Stream Surface North Wall can be roughly defined at the sharp transition zone from yellow pixels to blue pixels.

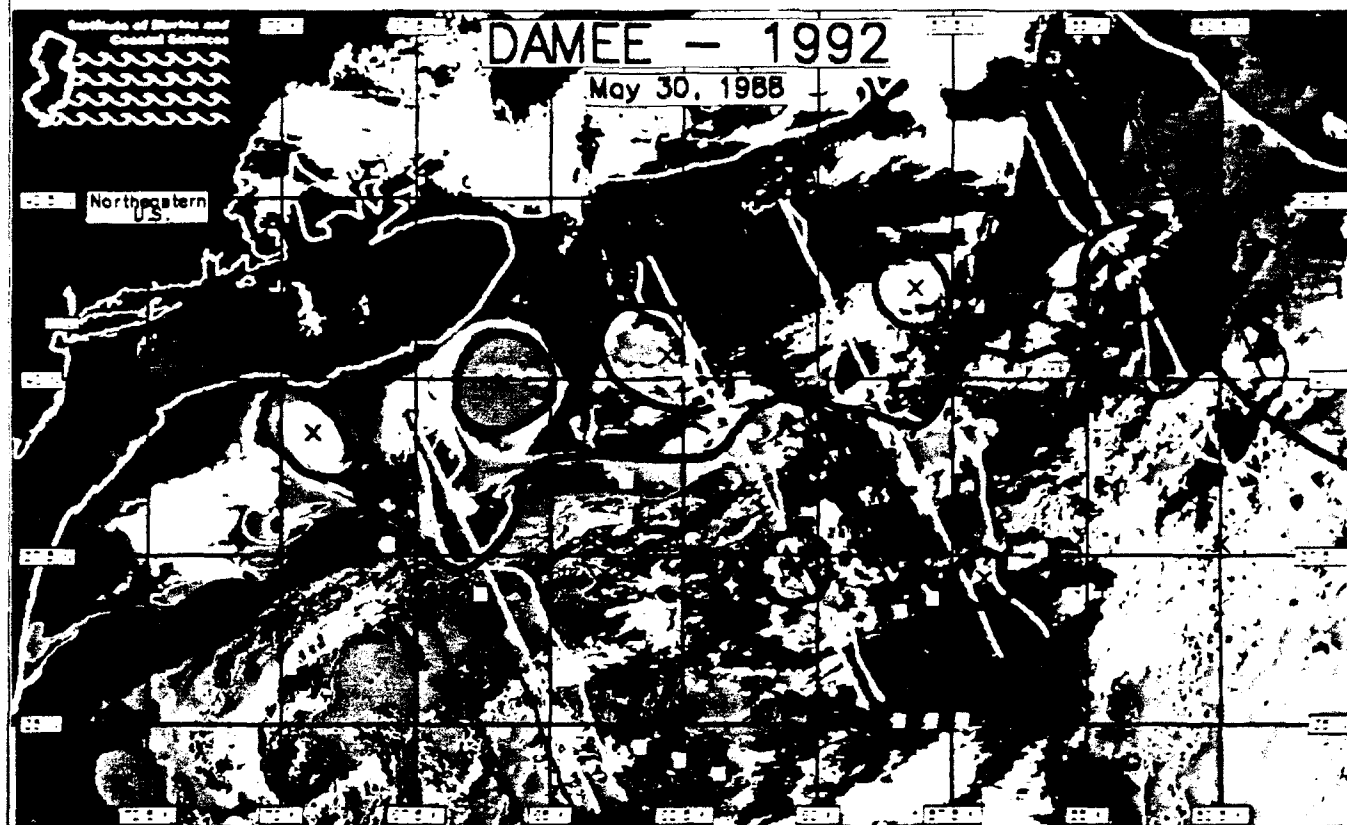


Figure 14. Composite satellite image, GEOSAT altimetry analysis and Gulf Stream analysis for 30 May 1988.

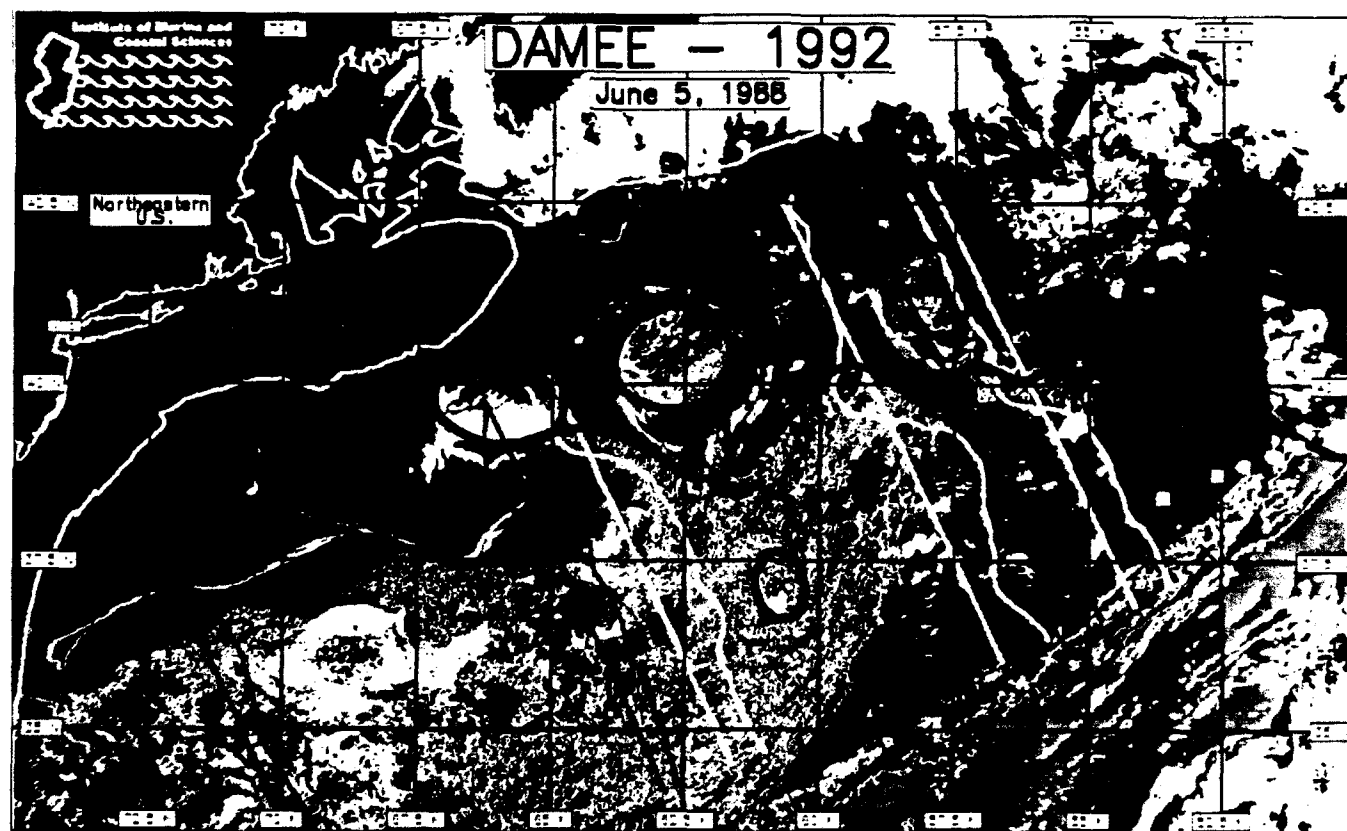


Figure 15. Composite satellite image, GEOSAT altimetry analysis and Gulf Stream analysis for 5 June 1988.

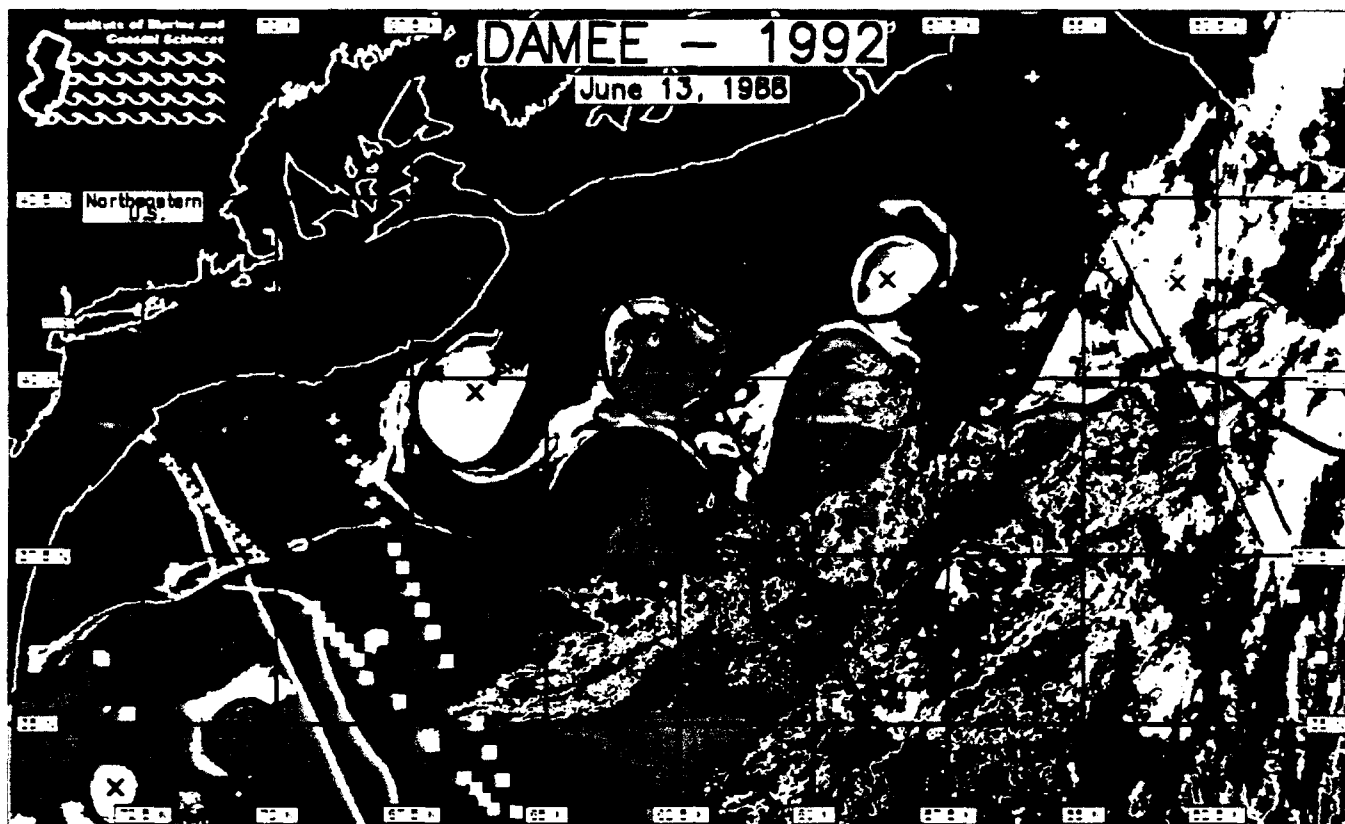


Figure 16. Composite satellite image, GEOSAT altimetry analysis and Gulf Stream analysis for 13 June 1988.

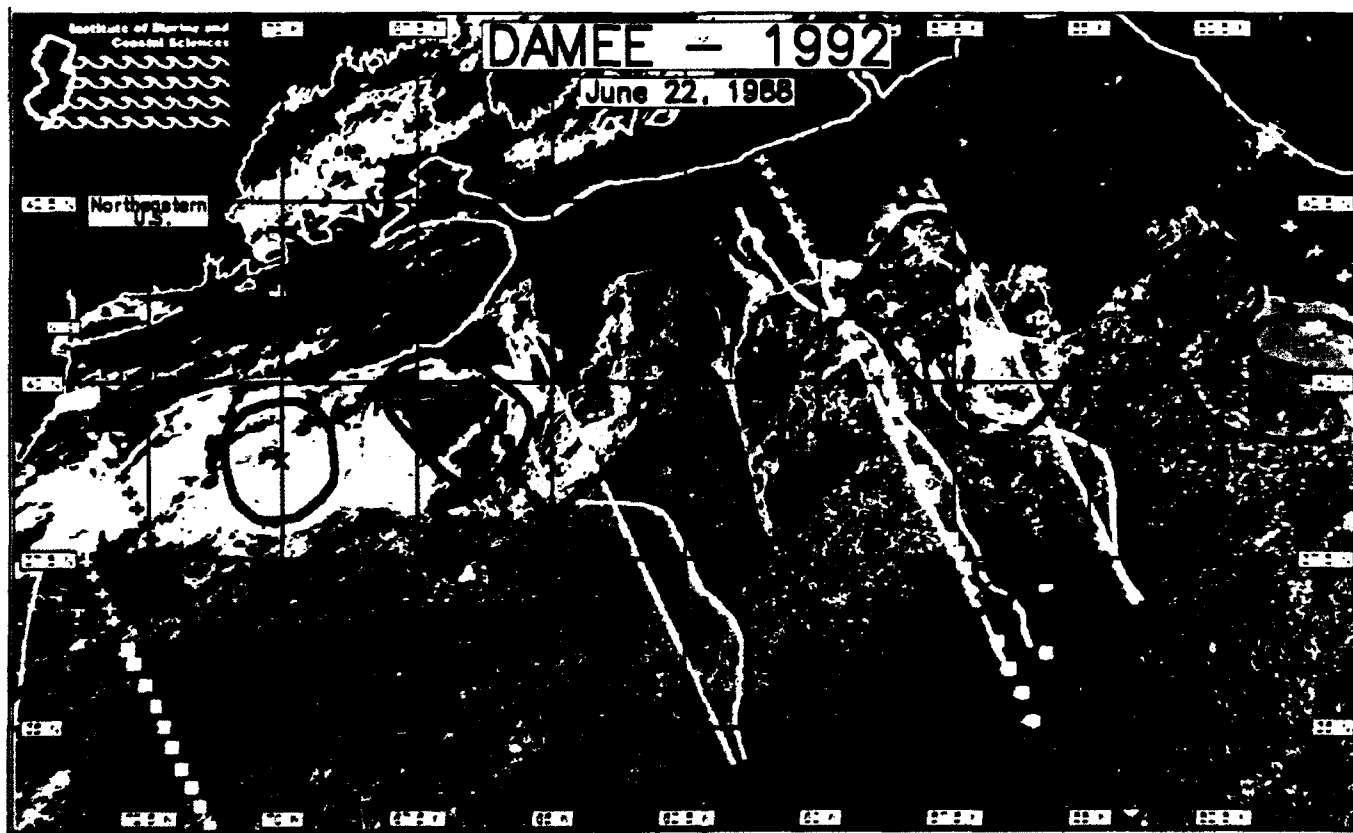


Figure 17. Composite satellite image, GEOSAT altimetry analysis and Gulf Stream analysis for 22 June 1988.

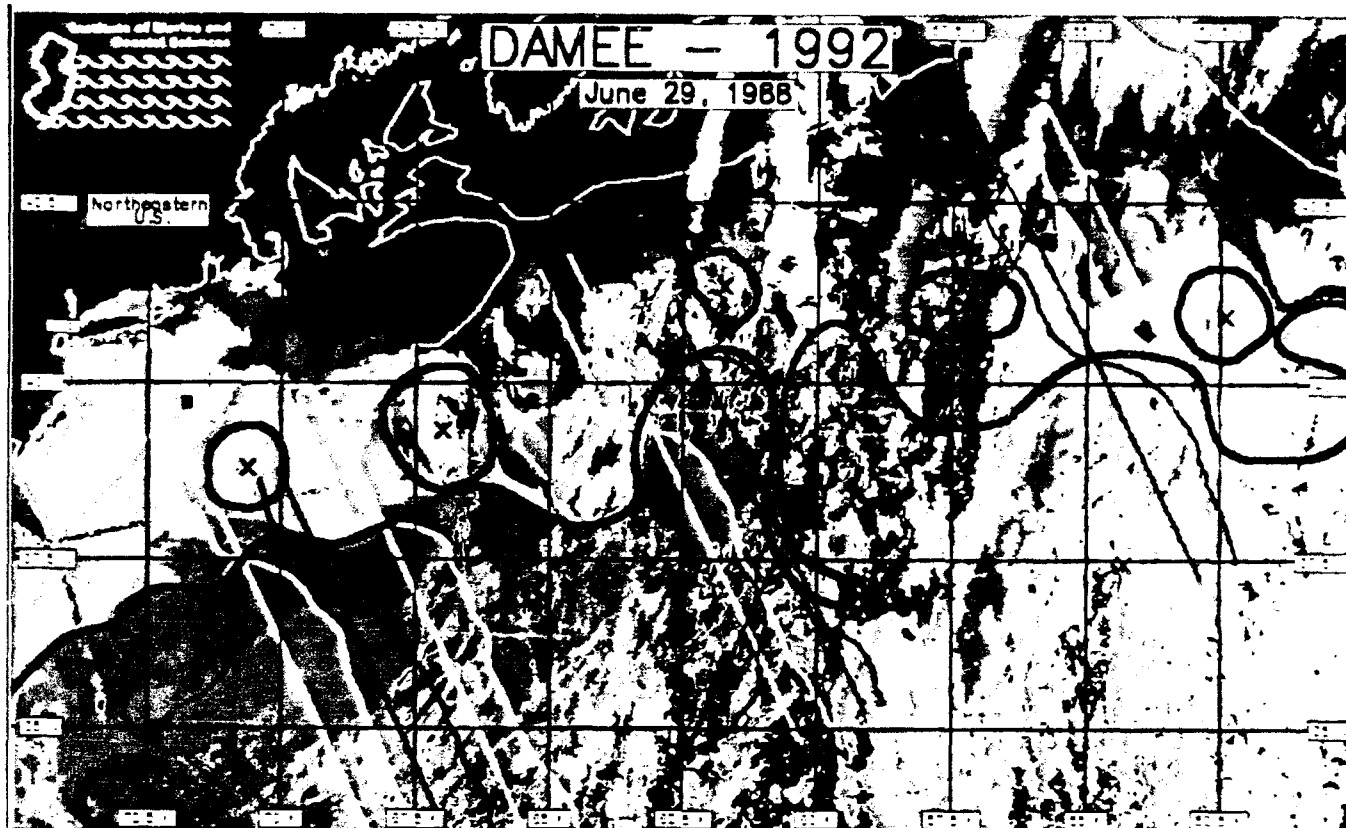


Figure 18. Composite satellite image, GEOSAT altimetry analysis and Gulf Stream analysis for 29 June 1988.



Figure 19. Composite satellite image, GEOSAT altimetry analysis and Gulf Stream analysis for 4 July 1988.

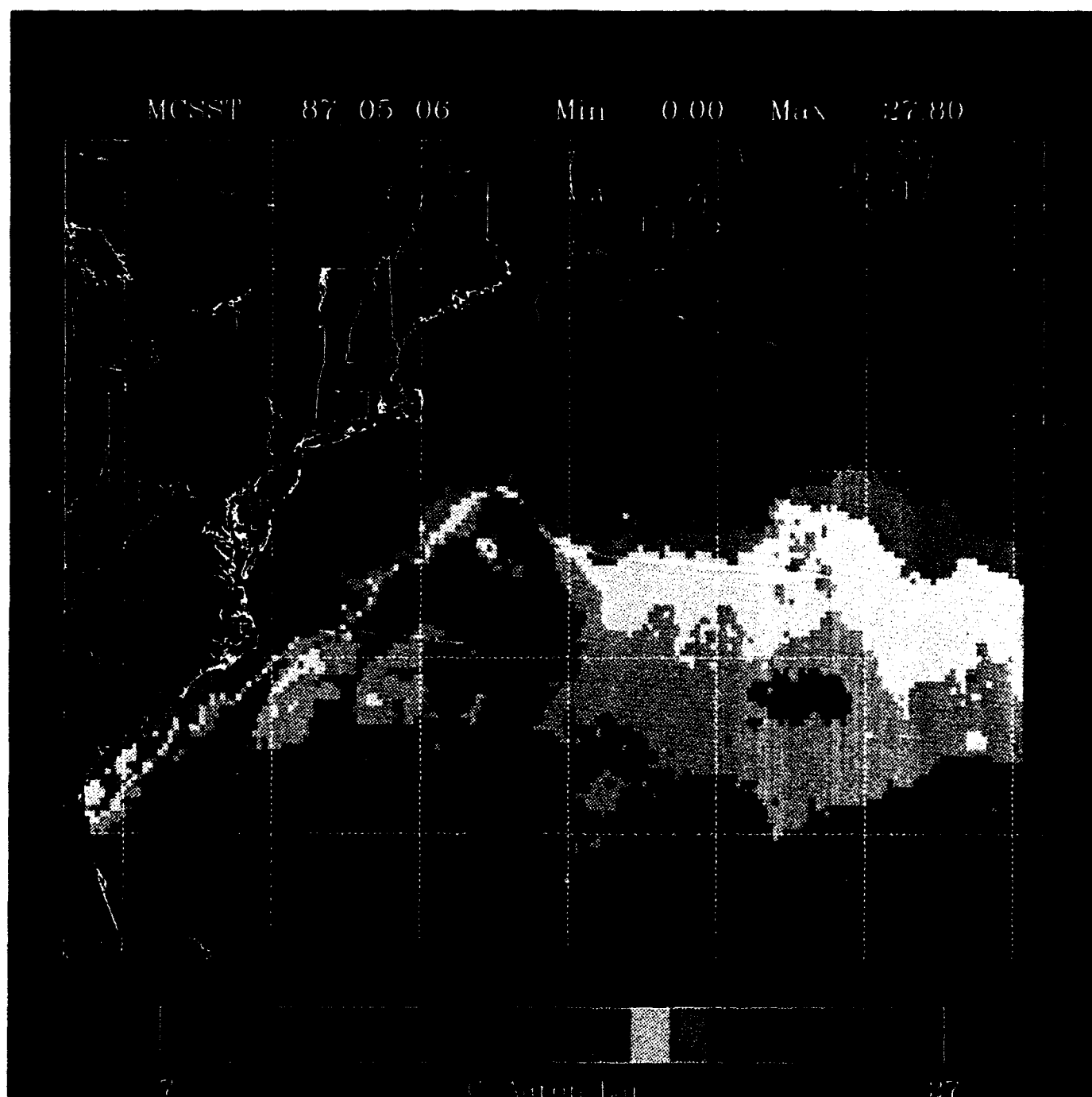


Figure 20. MCSST field on 6 May 1987.

The MCSST field provides some mesoscale texture inside the Sargasso water mass. Since MCSST is used in OTIS to create "super-observations", its mesoscale texture reflects on the OTIS analysis of SST. In the early phase of DAMEE, the MCSST data were prepared by one DAMEE participant who made a mistake in temporal interpolation. Therefore, most of the MCSST fields (not shown) input to OTIS were wrong and rejected by the quality control scheme in OTIS. This resulted in a vast majority of climatology-based super-observations and a lack of meso-scale texture in SST (see Figure 21) and salinity fields.

The complete set of MCSST fields for all cases are shown in the upper-right panel of figures at the end of Subsection III.B. (Figures 26 -- 41).

4. XBT

Although OTIS takes ship observations, fixed and drifting buoys' data and coastal marine station observations as input, the only in-situ data used in this DAMEE is the XBT (AXBT, CTD). Even after collecting all NAVOCEANO, NOARL REX, and special GEOSAT ground track AXBT, there were still only a few XBTs available near the date of each DAMEE case. Because XBT data usually contains many errors, vigorous quality control was necessary before it could be used in the analysis. NODC XBTs during those DAMEE case periods were available but were not used in the OTIS analysis because a high percentage of XBTs were found to be no good. The rest of the good NODC profiles are redundant with those collected from special field programs. Therefore, the way to supply enough XBTs to OTIS was by widening the temporal window. A 60-day temporal window, centered at the central date of each case, was used in the OTIS analysis. However, a narrower window was used to check the Gulf Stream front location. A large portion of XBTs used in DAMEE are GEOSAT ground track AXBTs. If the analysis of GEOSAT altimetry is reliable, the AXBTs become redundant in the process of identifying the Gulf Stream location.

Because of the sparseness of XBT, the horizontal temperature field was mostly influenced by MCSST. But, XBTs helped to construct the vertical structure of a front when they were close to the Gulf Stream. They were especially important to identify the submerged cold rings.

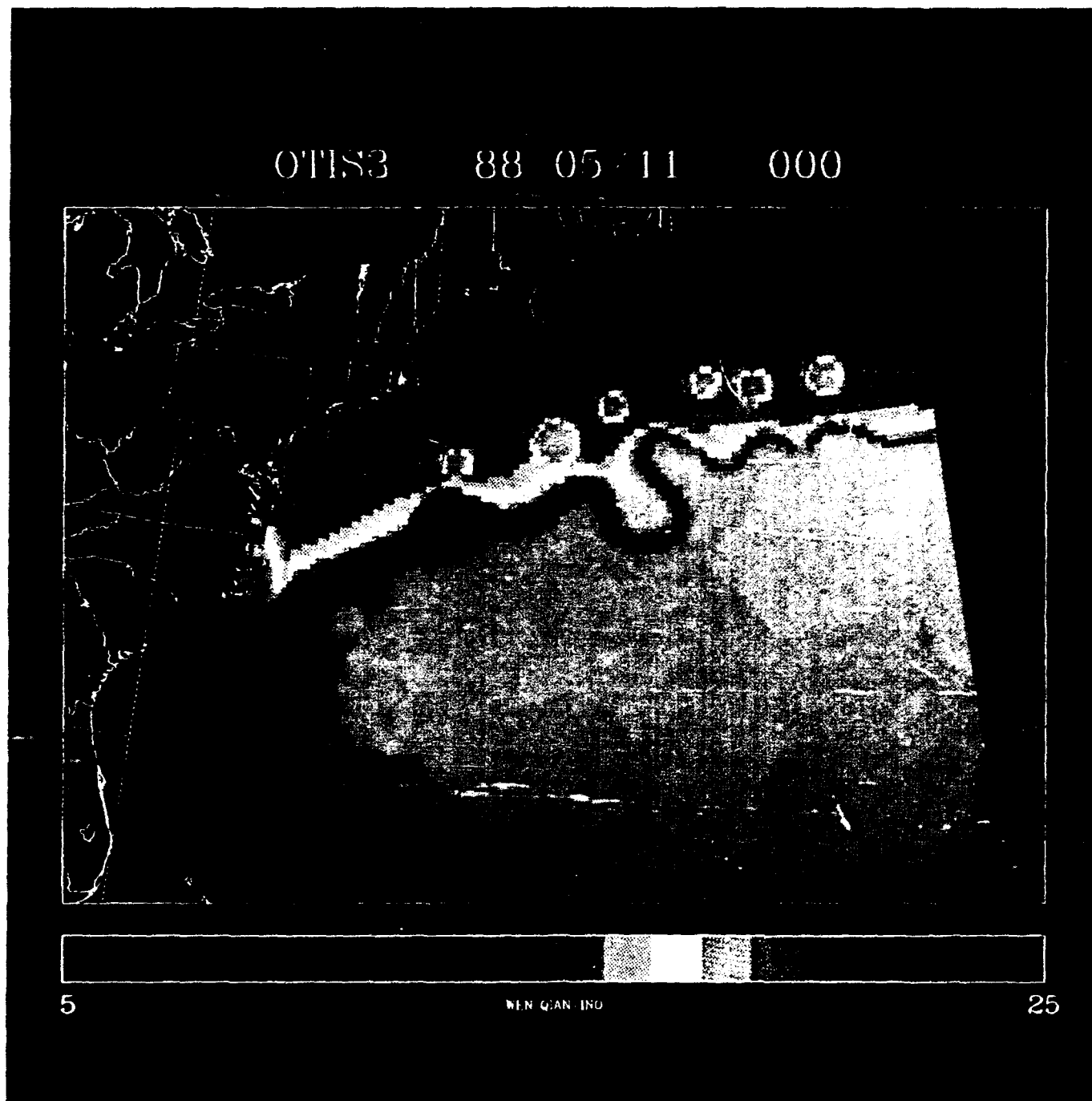


Figure 21. OTIS temperature analysis at 0 m (surface) obtained with incorrect MCSST input.

Figure 22 shows the locations of all XBTs during June 1988. The temperature at 200 m of the profile is color-coded. All of these XBTs and other XBTs that fell within the 60-day window were used in the OTIS analyses of Phase II cases. The lower-right panel of Figures 26 -- 41 at the end of Subsection III.B shows the locations and surface temperatures of XBTs used in each OTIS analysis.

5. GDEM-like climatology

GDEM-like climatology supplies OTIS with a 3-D background (first guess) on which new observations are added before OI is executed. If no other information is provided to OTIS, the analysis looks like a climatology of the Gulf Stream.

GDEM-like climatology provides vertical profiles of temperature and salinity which bear the characteristics of the mixed-layer and thermocline for the top 400 m of water. The top 400 m vertical profile can be reconstructed from the coefficients of a polynomial stored in the GDEM-like climatology data sets. The rest of the profile is stored with values at standard levels. The spatial resolution of GDEM is 30', and there is one set for each season.

To prepare the GDEM-like climatology field for OTIS, one had to first interpolate the coefficients of the polynomial and the values at standard levels from GDEM grid and levels to OTIS grid and levels. In this process, bilinear interpolation was used. Since there are only four seasonal means (representing 15 Feb., 15 May, 15 Aug. and 15 Nov.), linear interpolation is used in time. Monthly SST was also linearly interpolated to the date of the OTIS analysis. Figure 23 shows the GDEM-like climatology temperature at the surface for 11 May (the year is irrelevant) in the Harvard model domain. The mesoscale features associated with the Gulf Stream and rings were completely lost in the smooth transition of temperature.

MCSST and GDEM are two competing data influencing the final OTIS analysis. Figure 24 shows the OTIS analysis of surface temperature and salinity for the Harvard model domain for 6 May 1987. This OTIS analysis was obtained with correct input of MCSST. Figure 25 shows the OTIS analysis for 13 May 1987 which was obtained with incorrect input of MCSST (see the subsection of MCSST for reason) during the early phase of

DAMEE. Because the rejection of the incorrect MCSST by OTIS, the analysis has a bias toward GDEM-like climatology. The temperature change for the vast area south of the Gulf Stream and to the west of 59°W is as big as 2 degrees in one week!

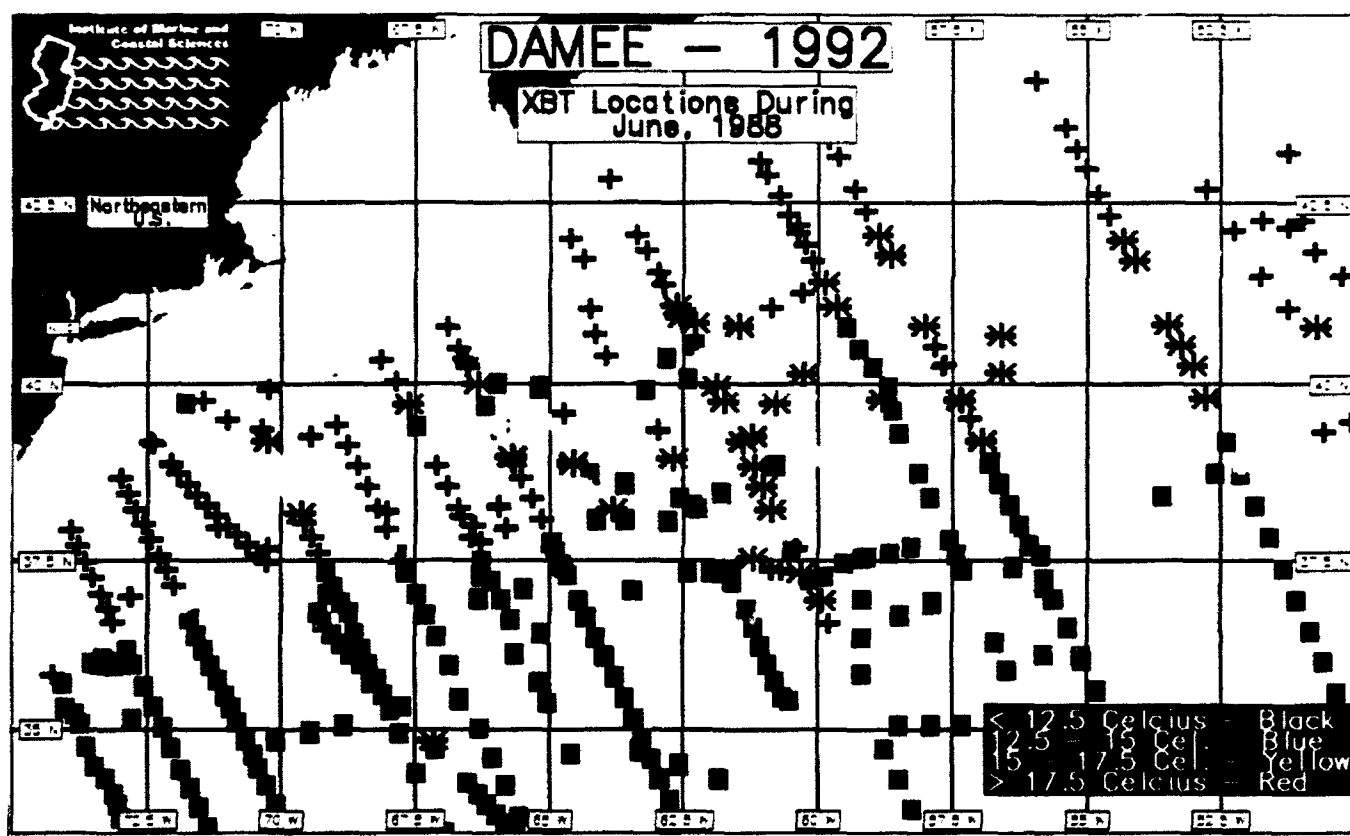


Figure 22. XBT locations and surface temperature during June 1988.

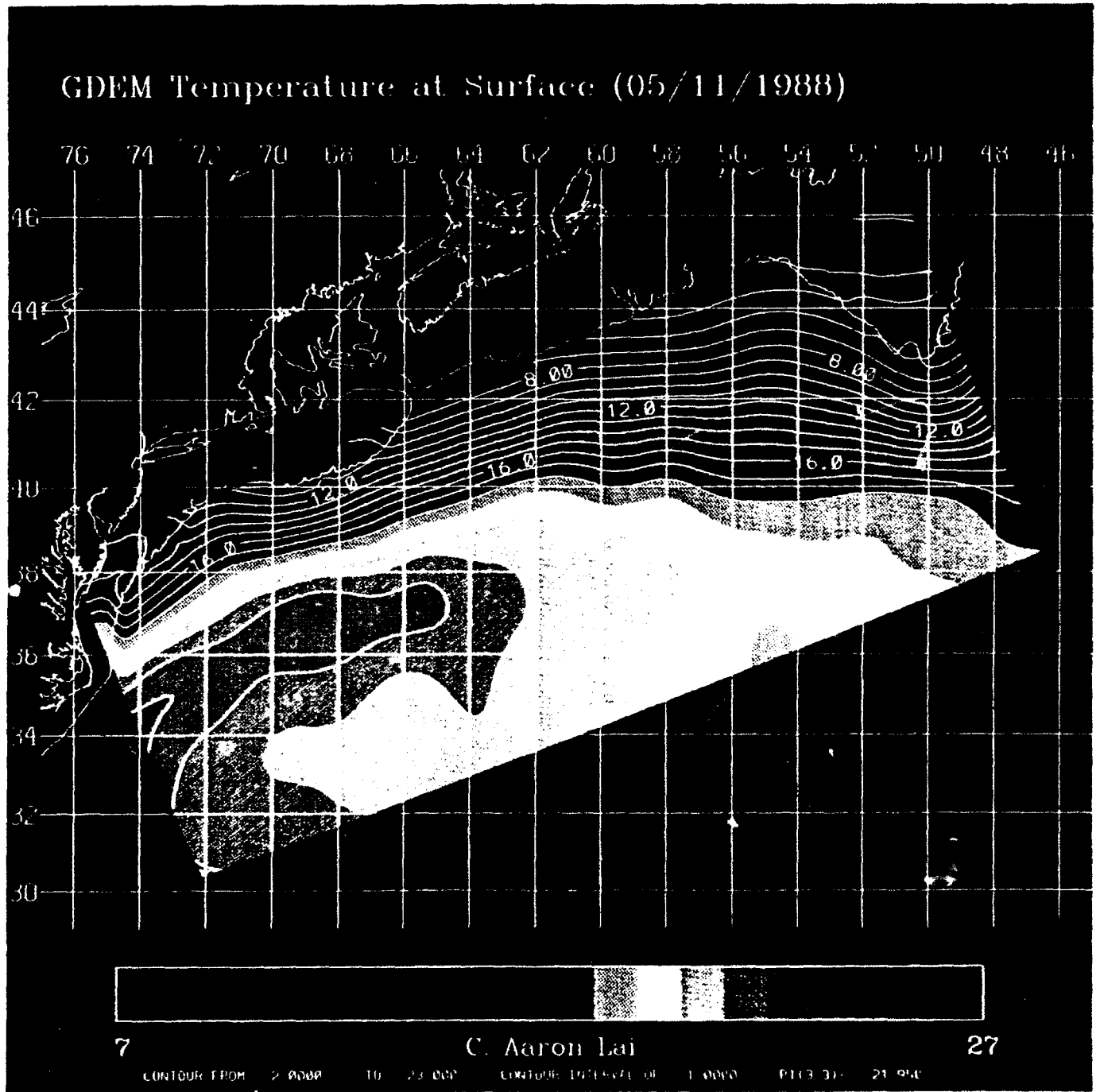


Figure 23. GDEM temperature at surface for 11 May.

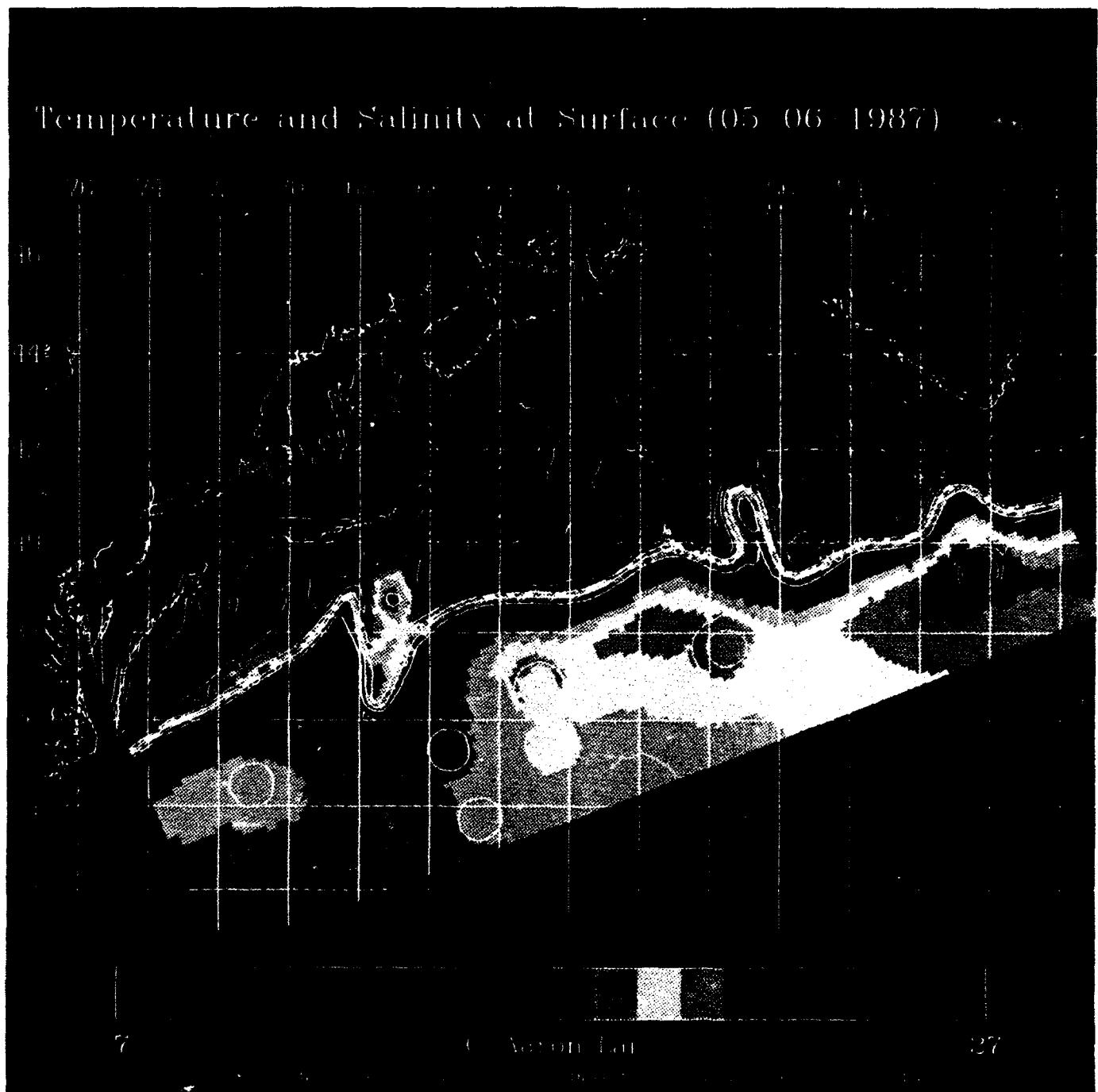
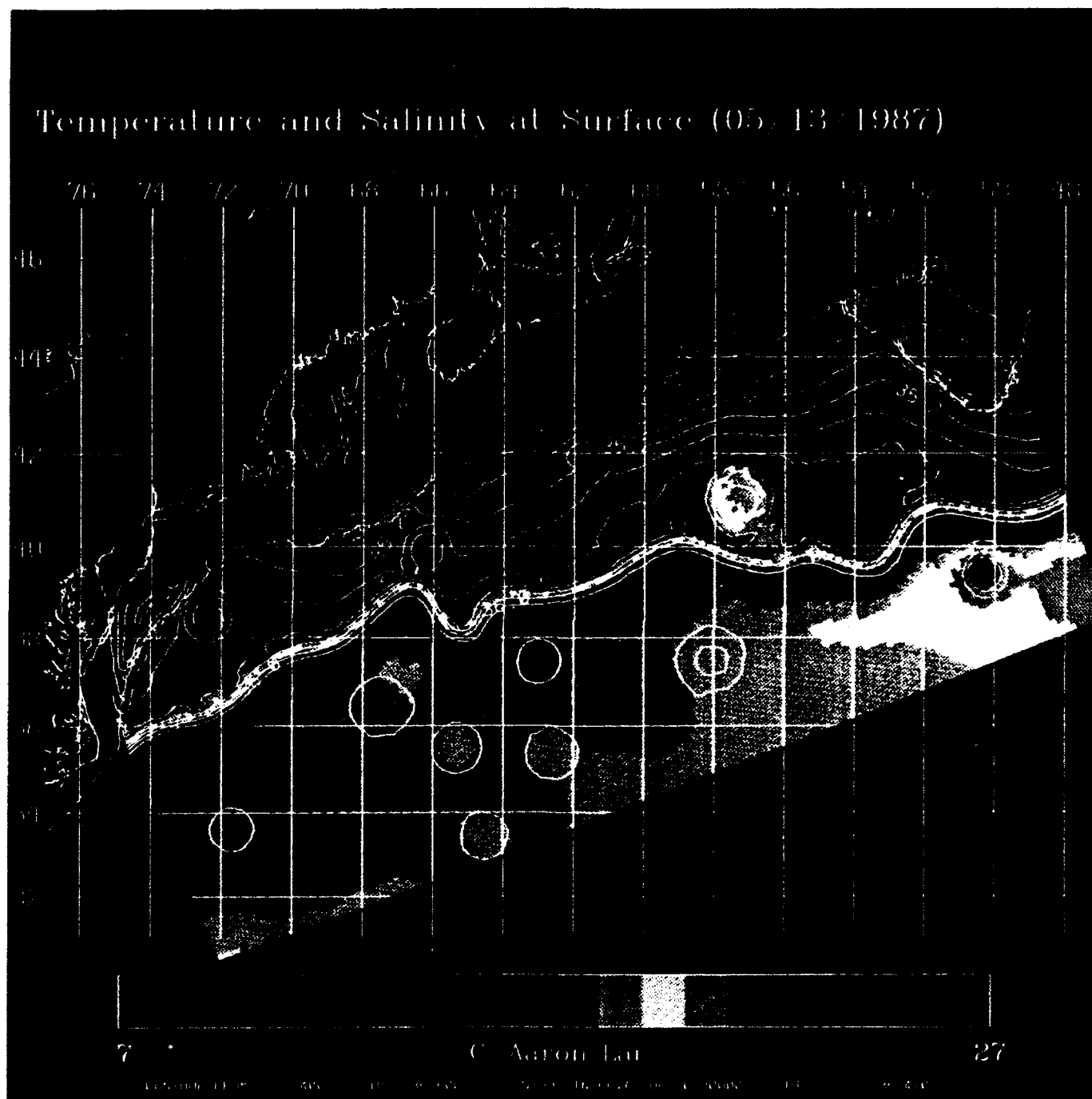


Figure 24. OTIS surface temperature and salinity for 6 May 1987.



**Figure 25. OTIS surface temperature and salinity for 13 May 1987.
Incorrect MCSST field was rejected by OTIS.**

Inputs to OTIS:

Inputs to OTIS include bogus information, MCSST, XBTs and GDEM-like climatology. Figures 26 -- 41 show the data of those types except GDEM-like climatology for every OTIS analysis date. OTIS-analyzed SST is presented at the upper-left panel of the same figure to facilitate the comparison between input and output temperatures.

C. Data output from OTIS

Outputs from OTIS include 3-D temperature, salinity, temperature error, temperature anomaly fields and 2-D surface dynamic height field. Temperature and salinity are the product of assimilating the observed data into a first guess (GDEM-like) field. The temperature error is essentially the Gaussian covariance field, and the temperature anomaly is the difference between the analysis and the climatology. Surface dynamic height is computed from the analyzed temperature and salinity profile. The level of no-motion is set at 2,000 m.

There are 34 levels in the vertical for each OTIS output profile. The depths of those levels are 0 m, 2.5 m, 7.5 m, 12.5 m, 17.5 m, 25 m, 32.5 m, 40 m, 50 m, 62.5 m, 75 m, 100 m, 125 m, 150 m, 200 m, 300 m, 400 m, 500 m, 600 m, 700 m, 800 m, 900 m, 1000 m, 1100 m, 1200 m, 1300 m, 1400 m, 1500 m, 1750 m, 2000 m, 2500 m, 3000 m, 4000 m, and 5000 m. Regardless of the actual bathymetry, all profiles are extended to 5000 m depth. The domain of OTIS output is bounded by 47°W and 82°W in the east-west direction, and by 47°N and 27°N in the north-south direction. Because the resolution is 12 minutes, there are 176 x 101 sets of temperature and salinity profiles in one OTIS analysis. Every set of profiles is labeled with its grid numbers, location (latitude, and longitude), surface dynamic height and mixed-layer depth. The sequence of the profiles is temperature, salinity, temperature error, and then temperature anomaly.

A FORTRAN subroutine to read the OTIS output file is given in Section V.

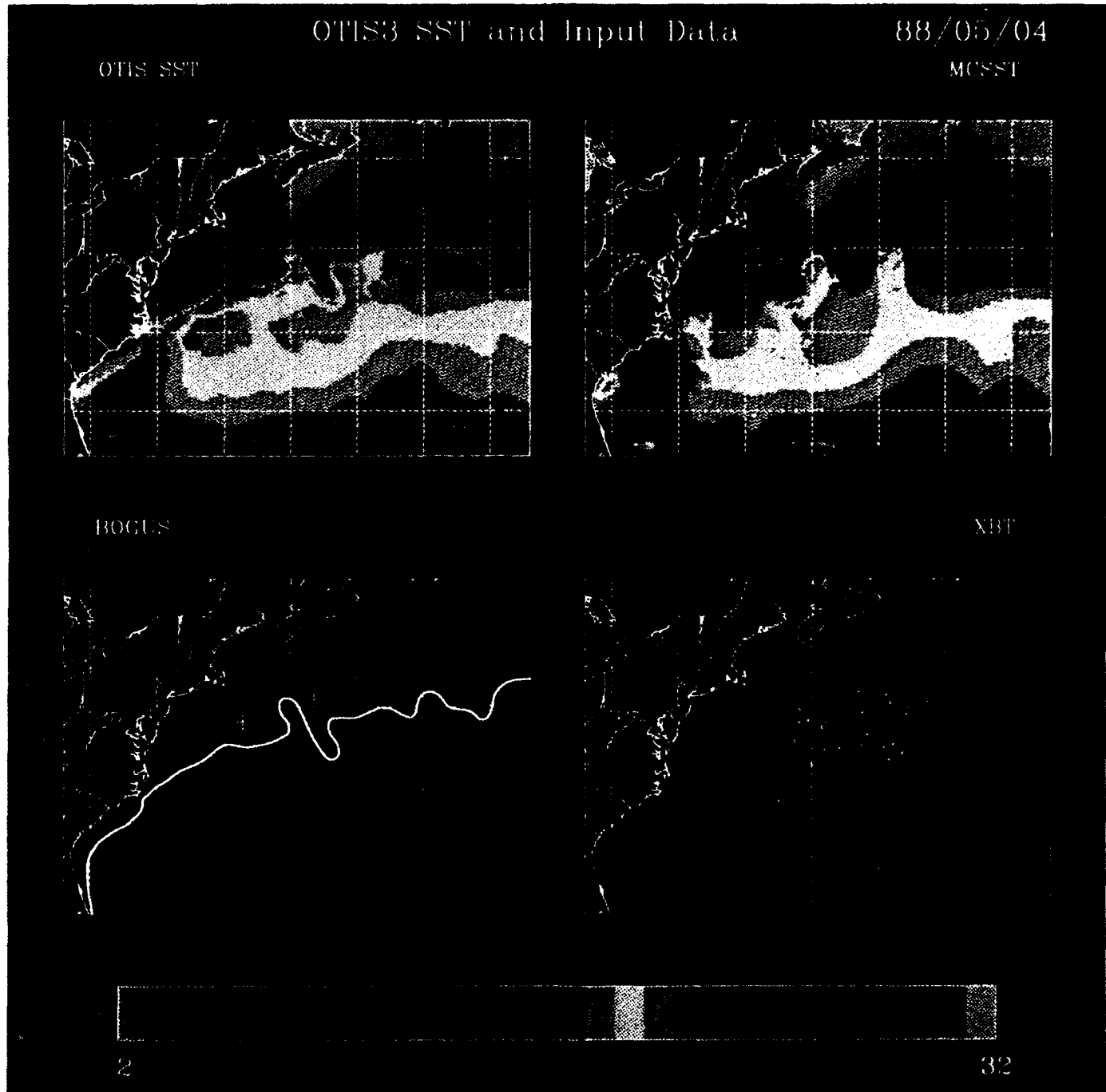


Figure 26. OTIS3 SST and input data for 4 May 1988.

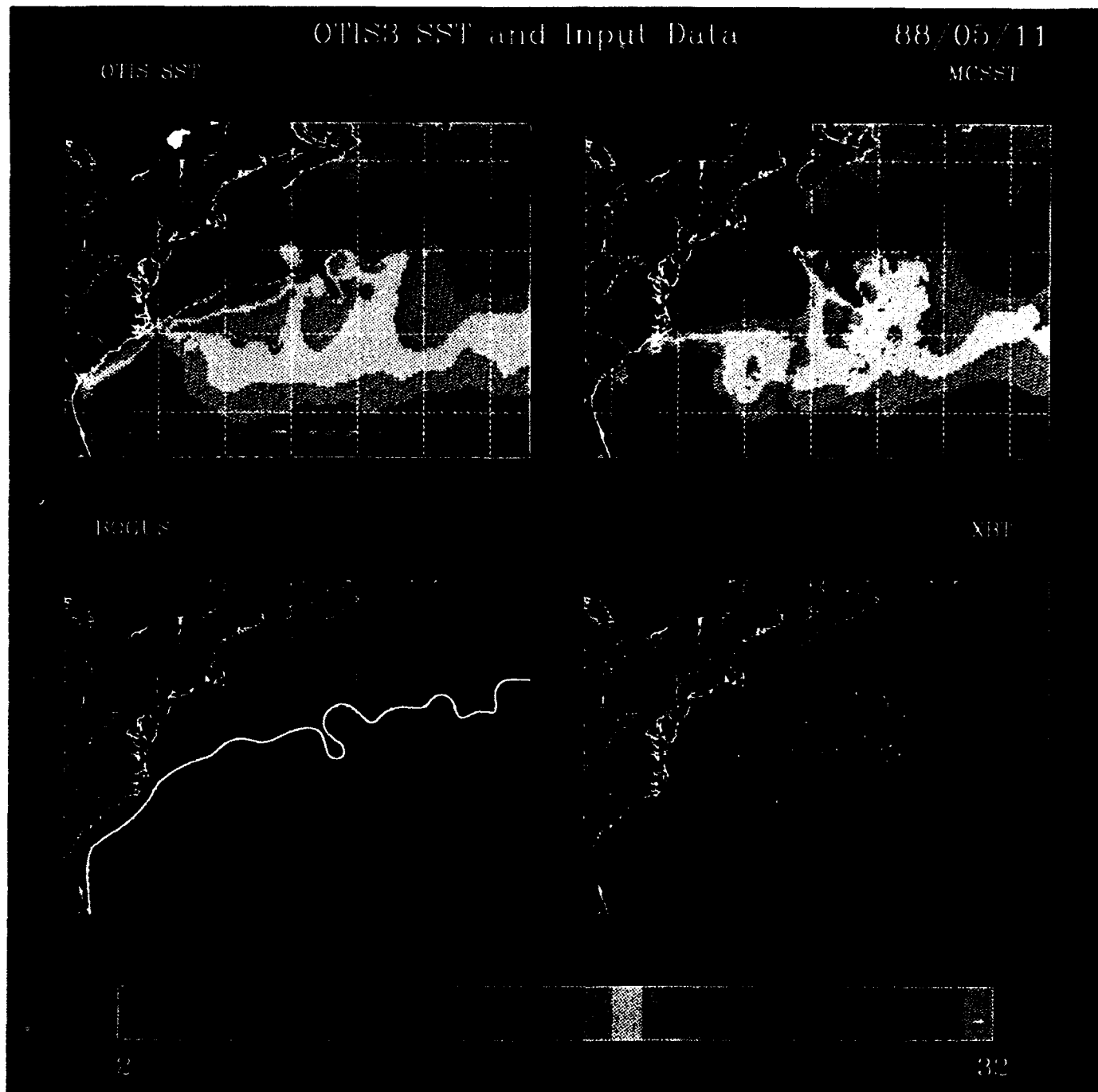


Figure 27. OTIS3 SST and input data for 11 May 1988.

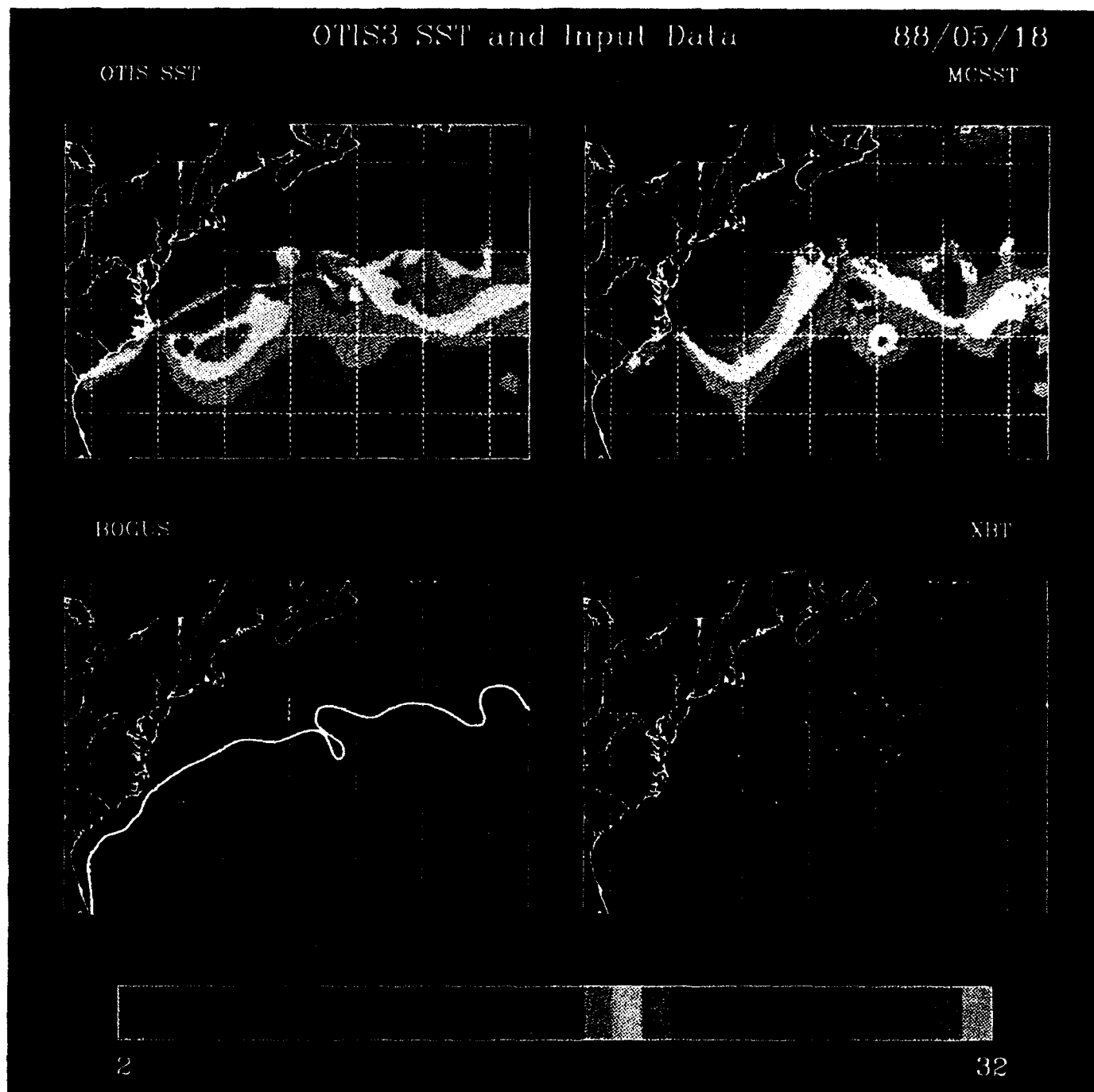


Figure 28. OTIS3 SST and input data for 18 May 1988.

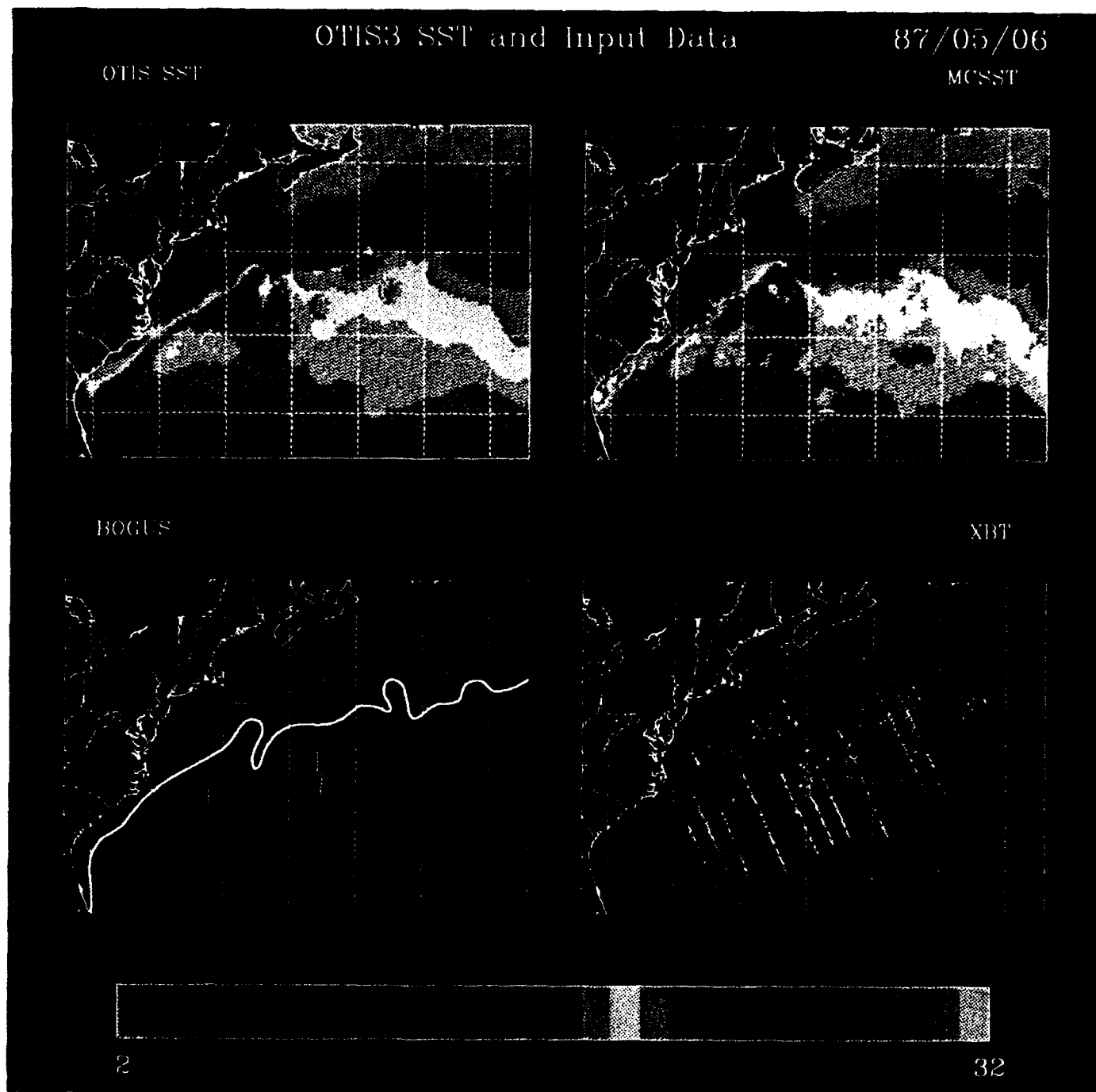


Figure 29. OTIS3 SST and input data for 6 May 1987.

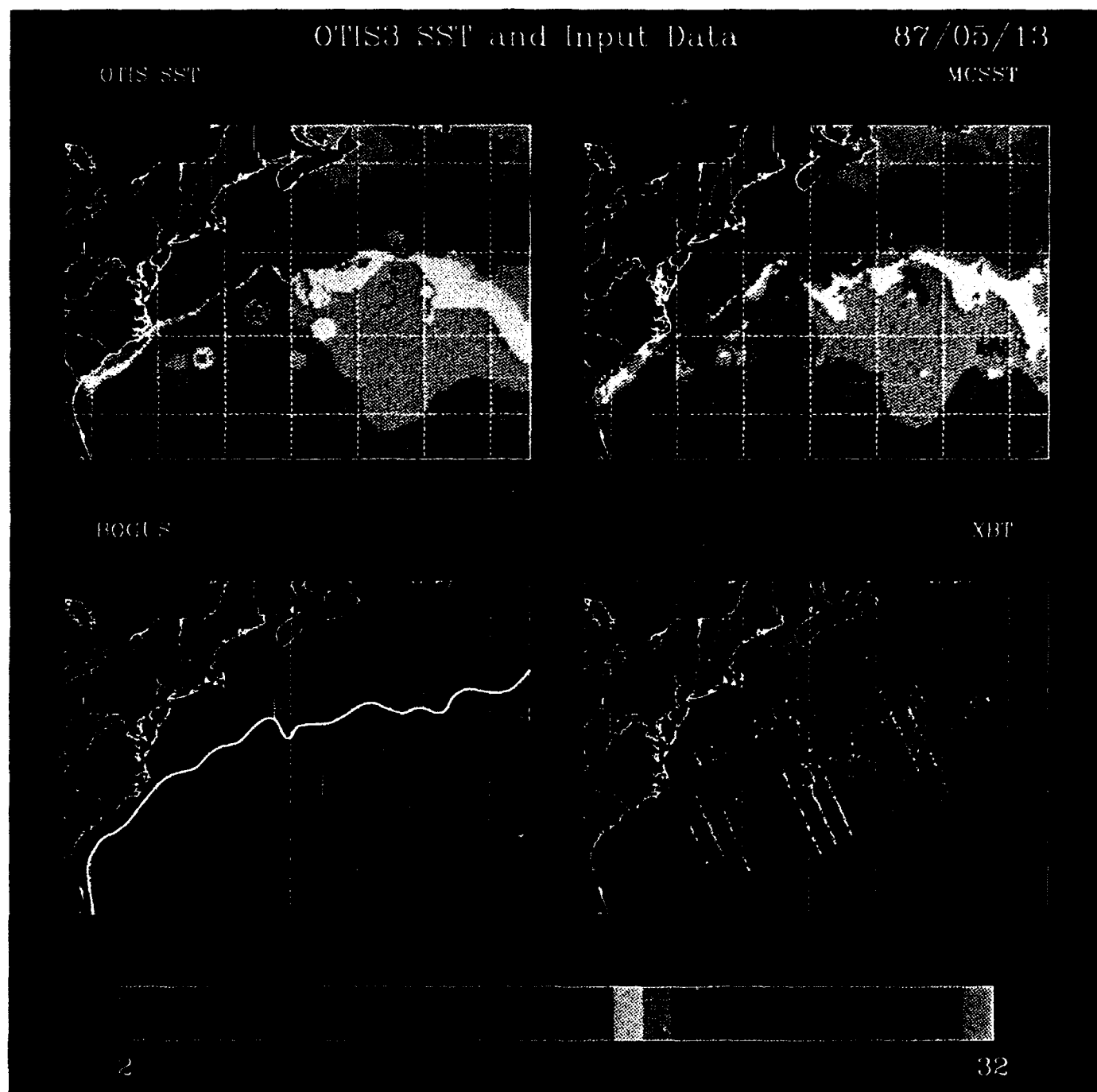


Figure 30. OTIS3 SST and input data for 13 May 1987.

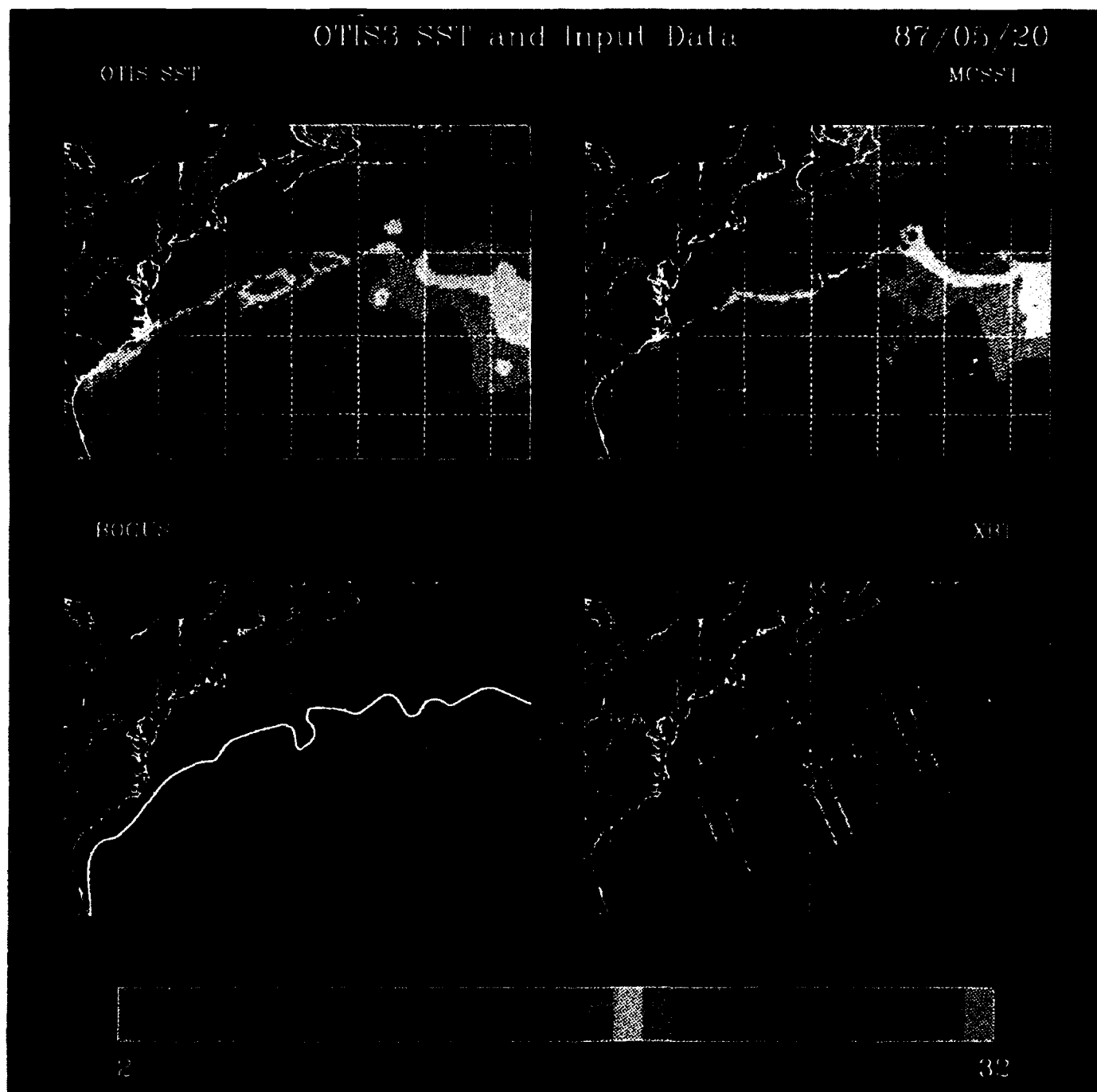


Figure 31. OTIS3 SST and input data for 20 May 1987.

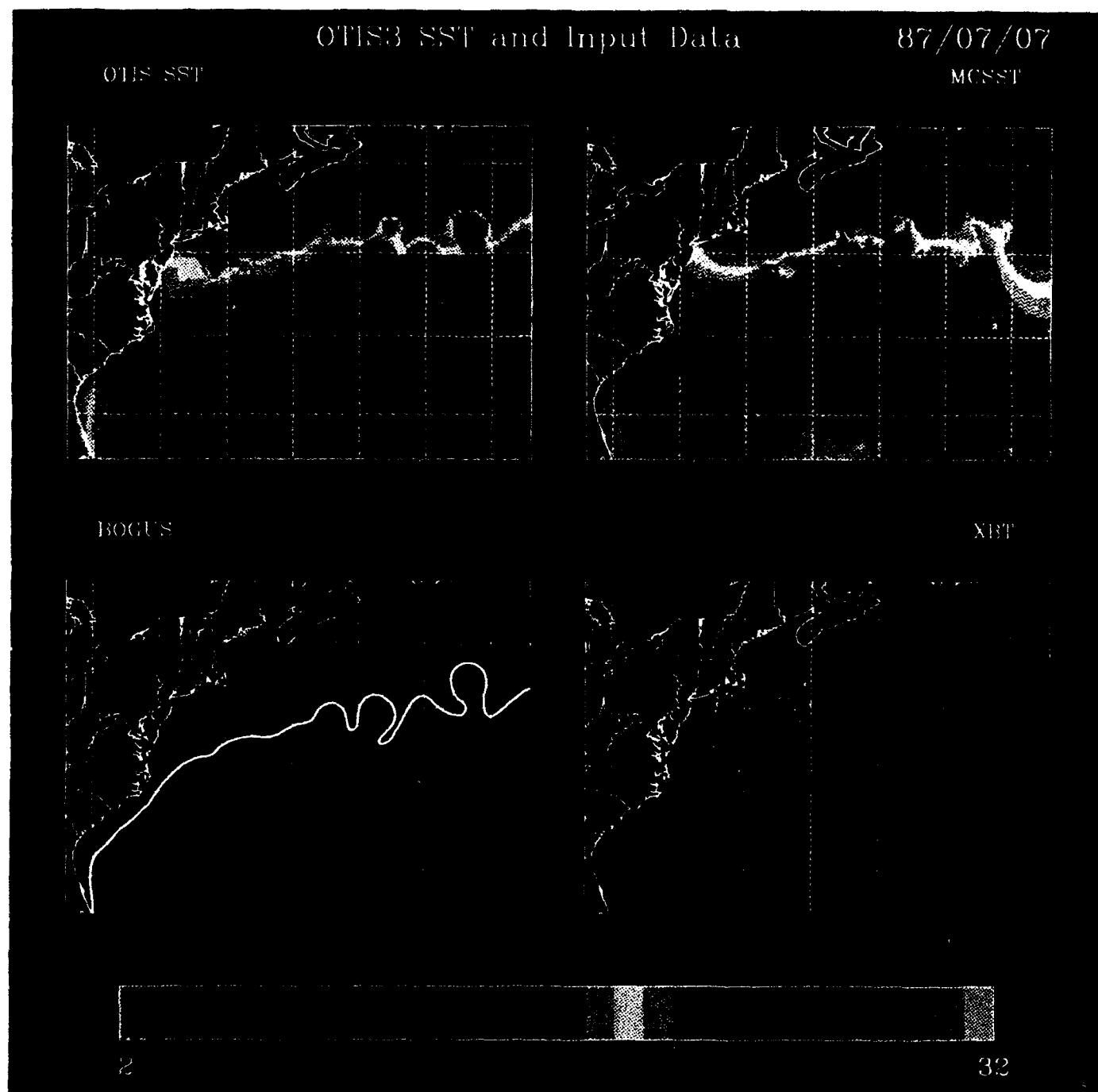


Figure 32. OTIS3 SST and input data for 7 July 1987.

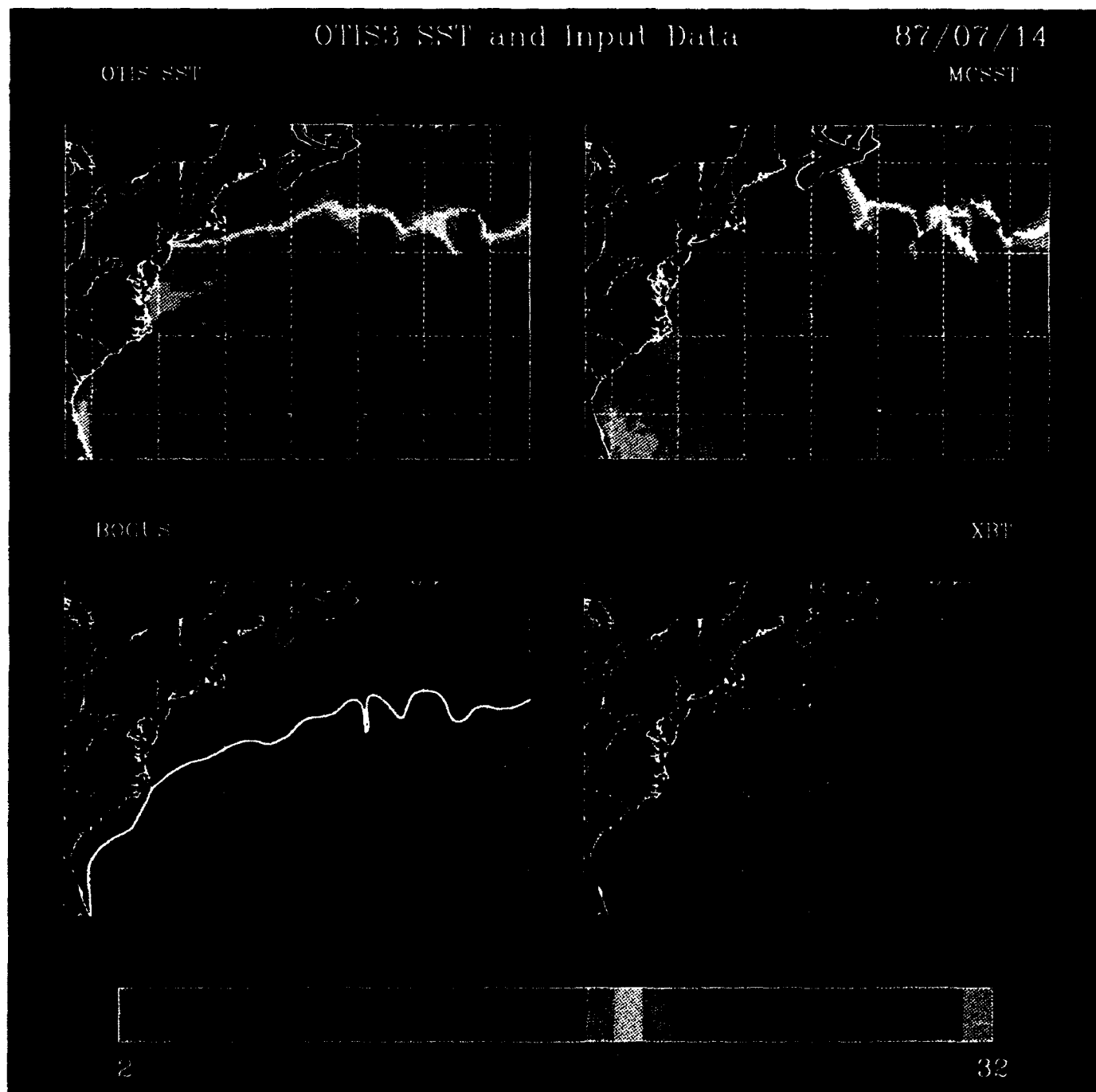


Figure 33. OTIS3 SST and input data for 14 July 1987.

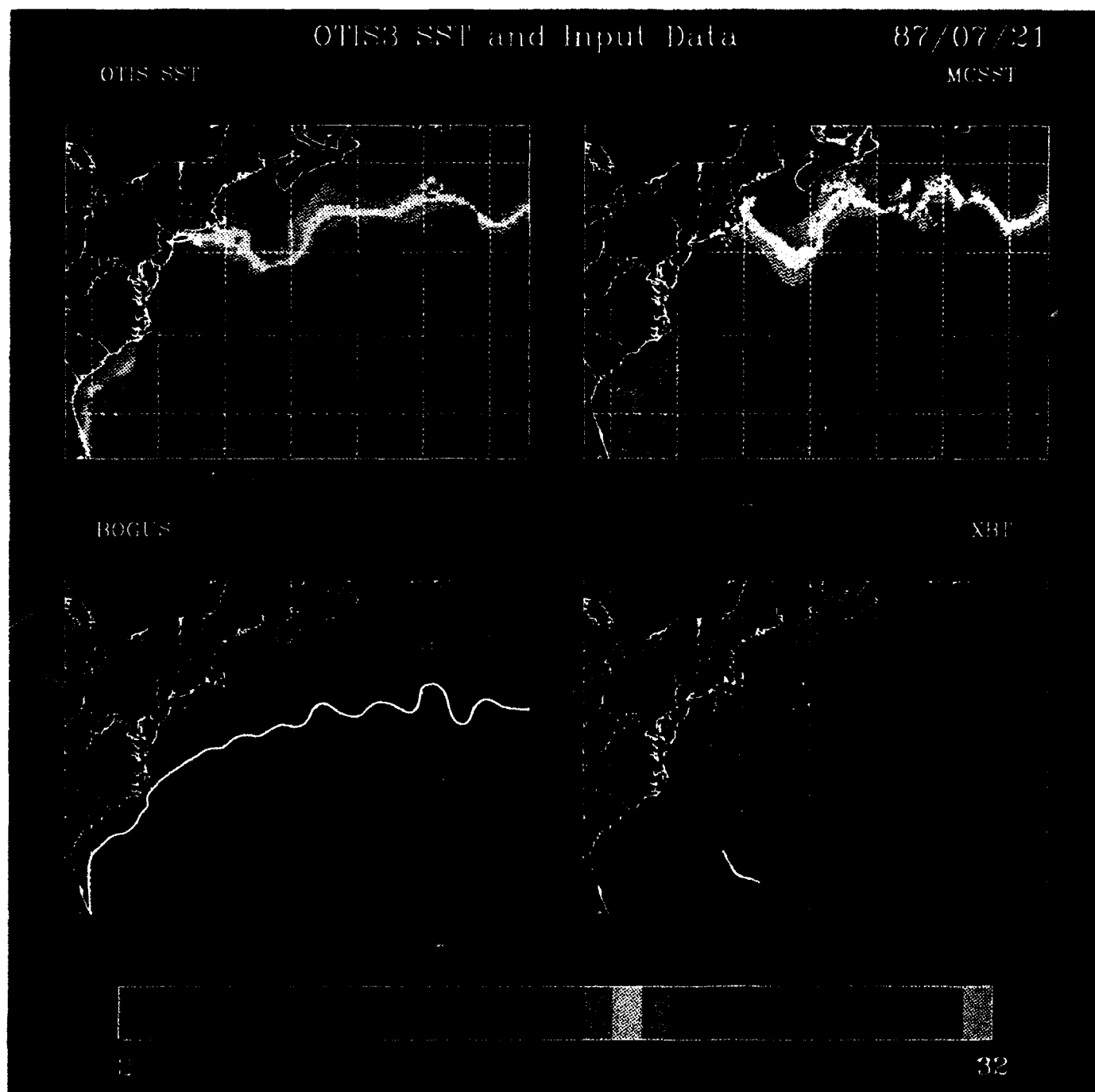


Figure 34. OTIS3 SST and input data for 21 July 1987.

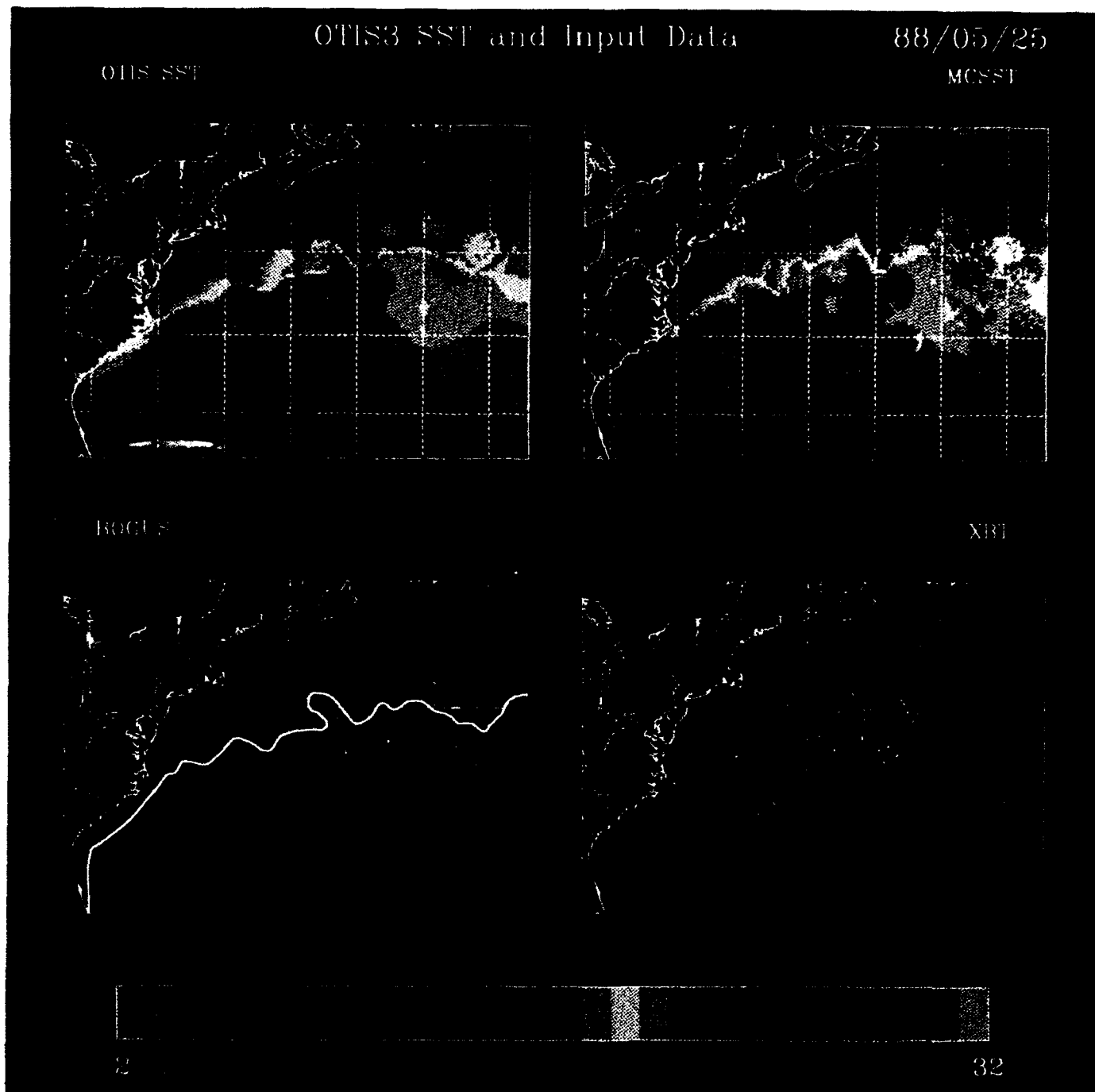


Figure 35. OTIS3 SST and input data for 25 May 1988.

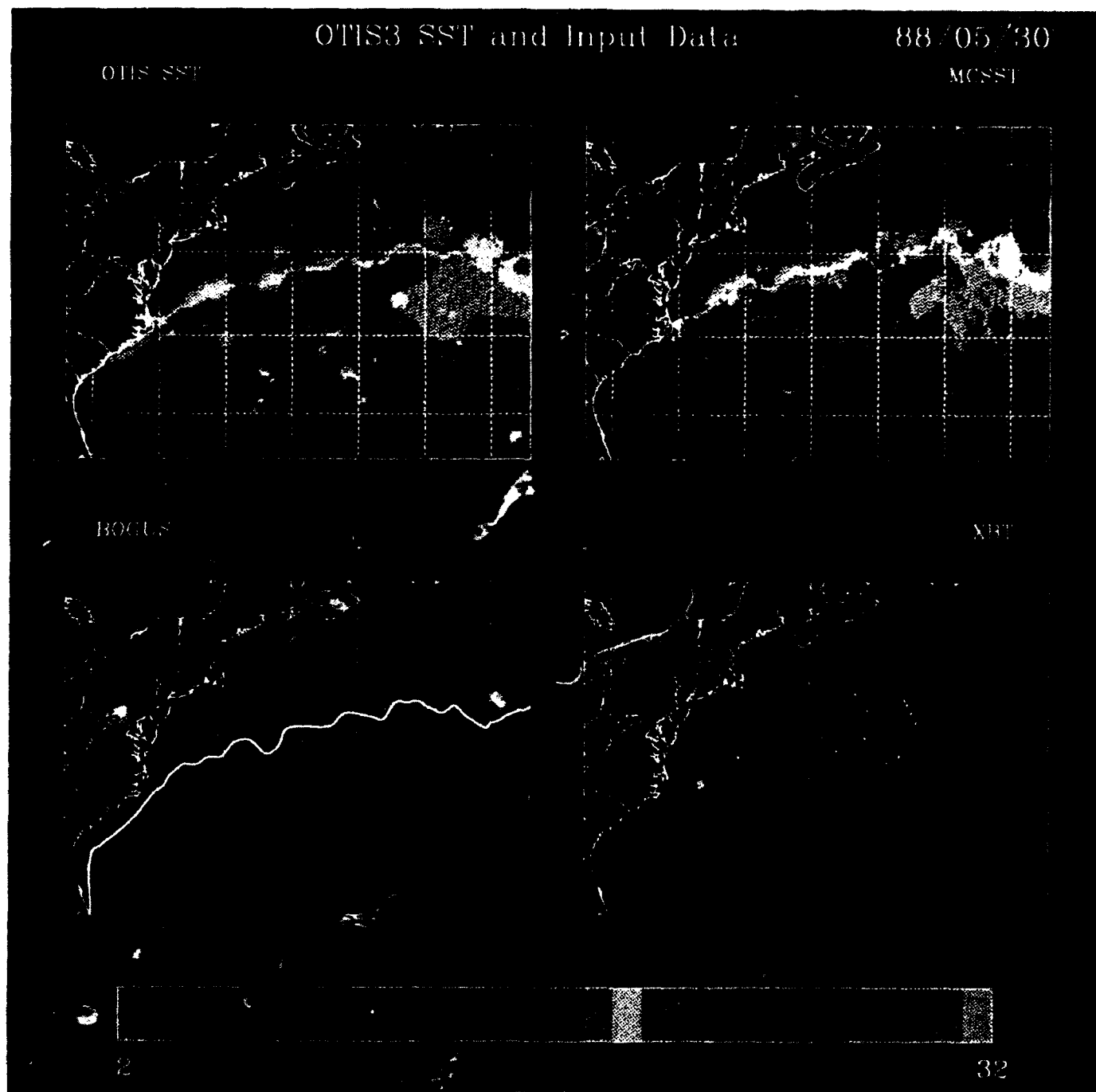


Figure 36. OTIS3 SST and input data for 30 May 1988.

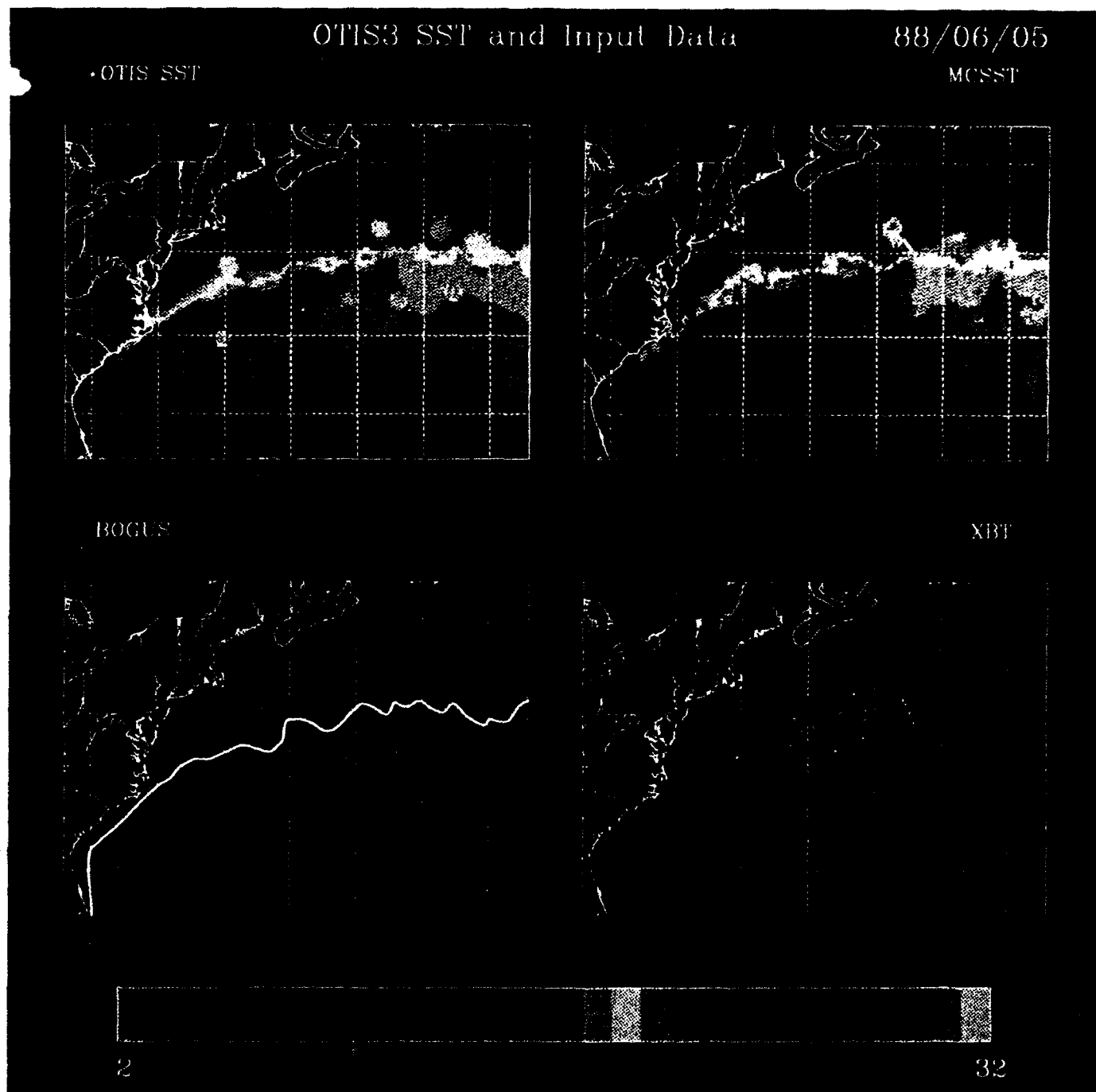


Figure 37. OTIS3 SST and input data for 5 June 1988.

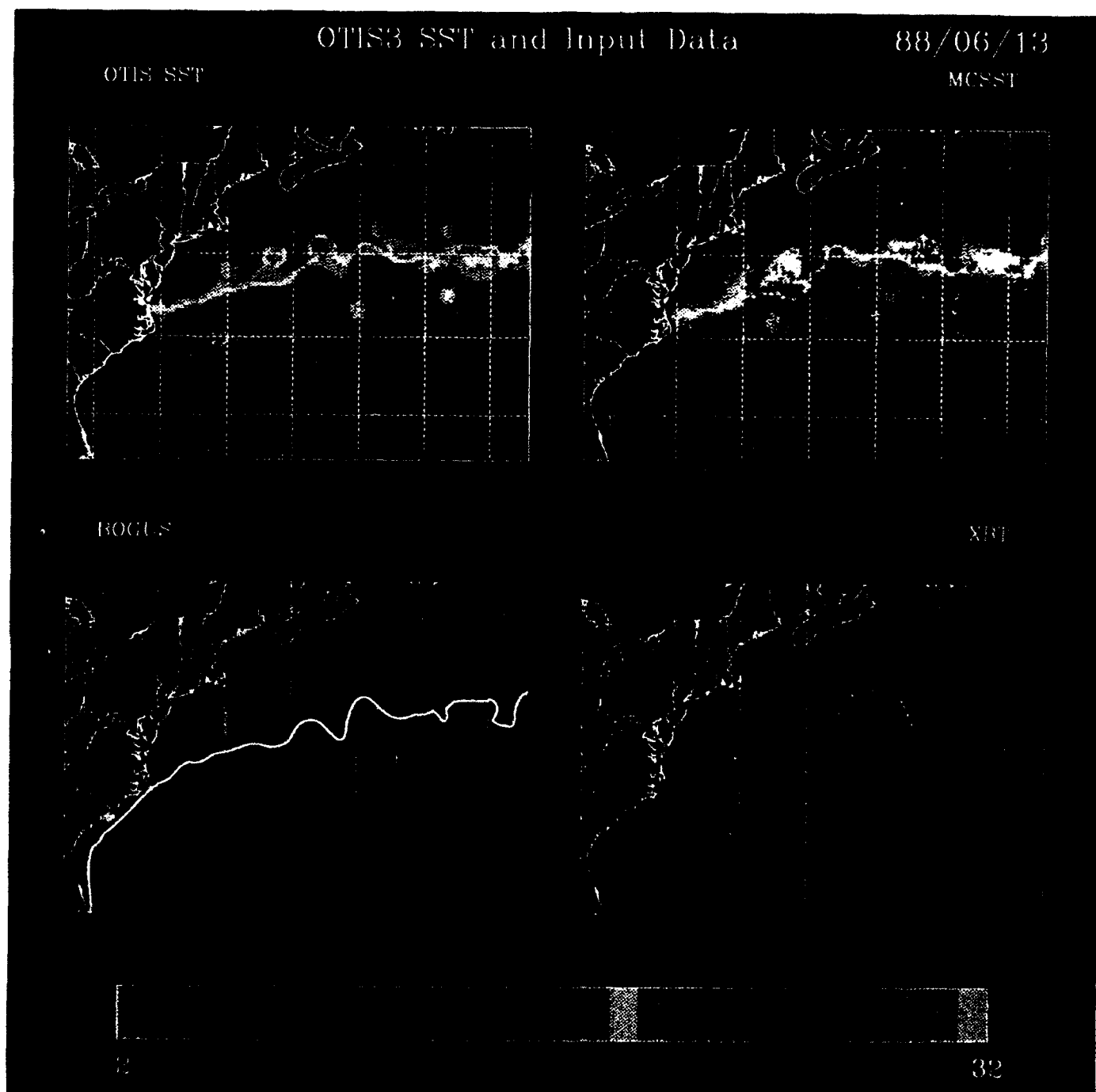


Figure 38. OTIS3 SST and input data for 13 June 1988.

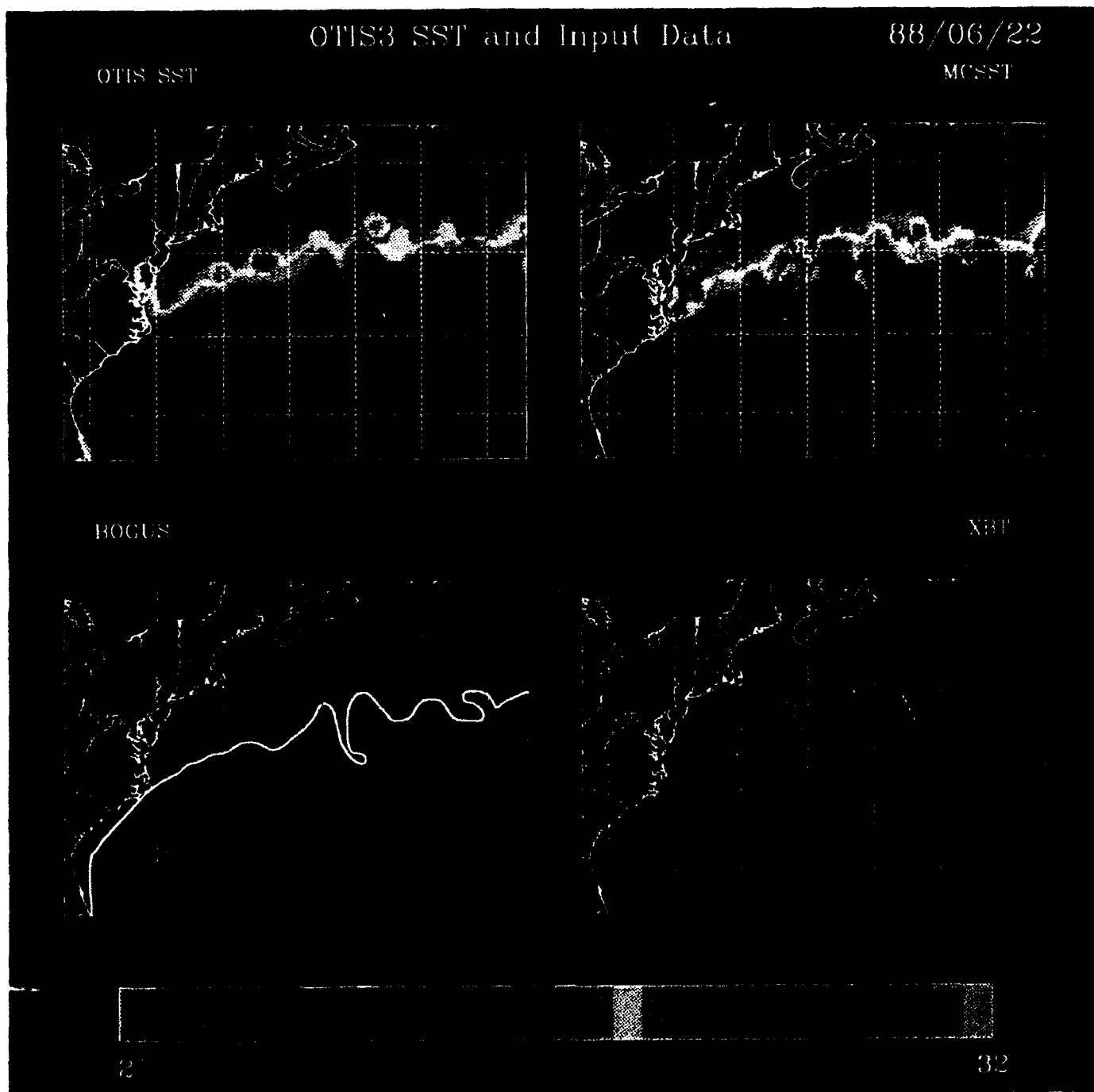


Figure 39. OTIS3 SST and input data for 22 June 1988.

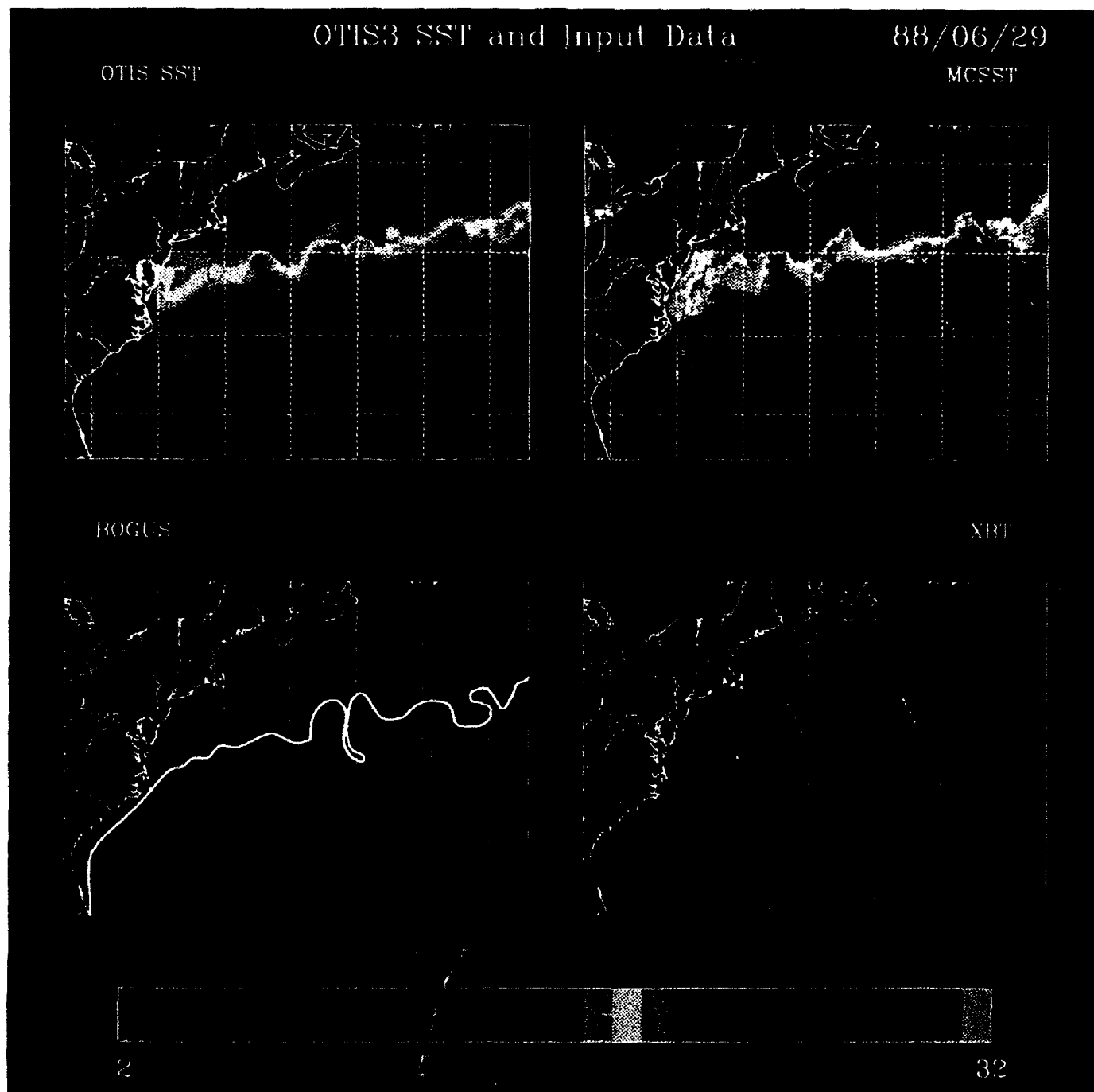


Figure 40. OTIS3 SST and input data for 29 June 1988.

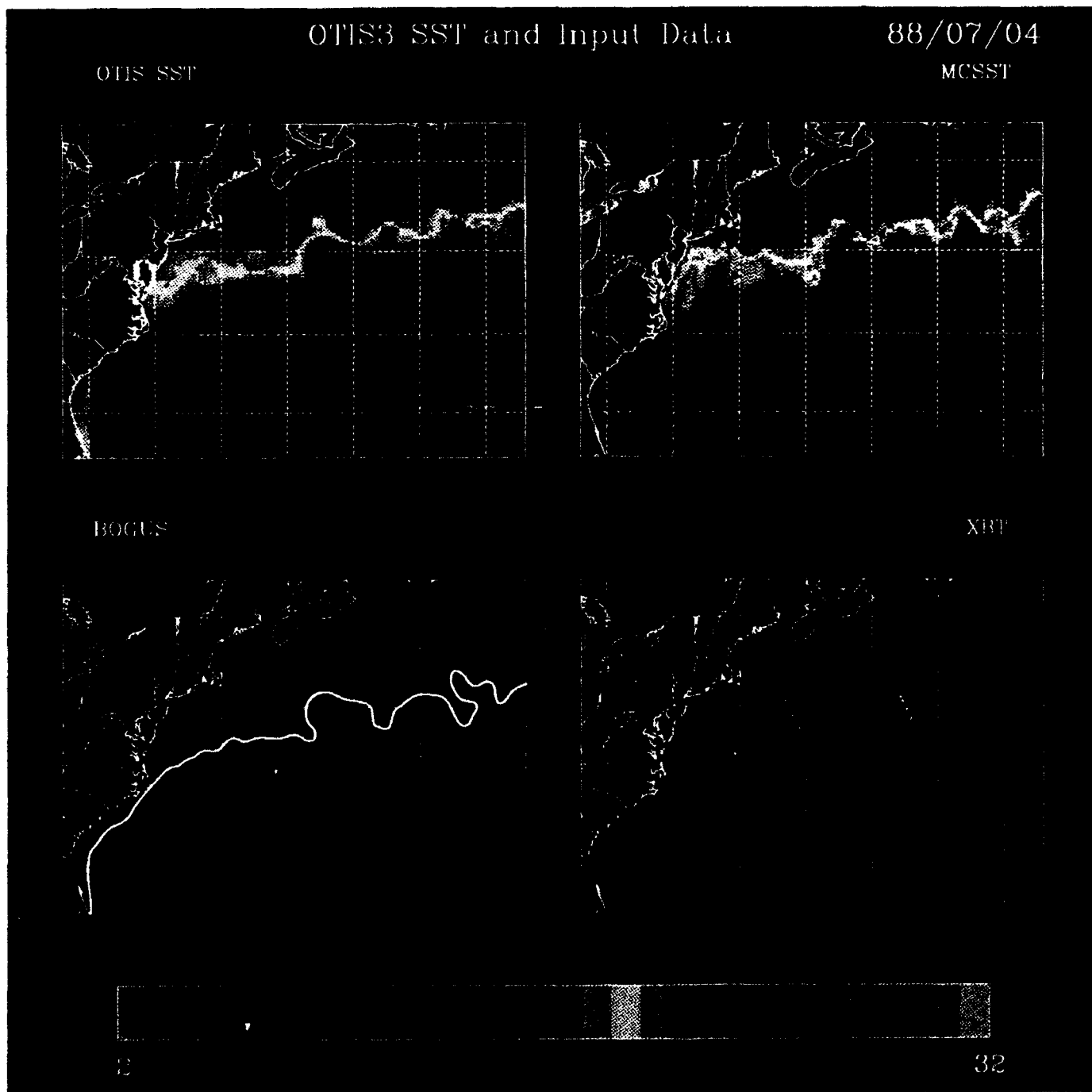


Figure 41. OTIS3 SST and input data for 4 July 1988.

1. 3-D temperature and salinity fields

Both the horizontal and the vertical sections are necessary to present an OTIS analysis of the Gulf Stream system. The horizontal 2-D section is a favorite because of the fixed domain. The size of a vertical section depends on the orientation of the cross section. Therefore, only horizontal sections are prepared here.

The OTIS analyzed SST is presented at the upper-left panel of each of Figures 26 -- 41. In most cases, the OTIS SST resembles input MCSST field. However, when there was a long period of extensive cloud coverage over a certain Gulf Stream area and the MCSST was obtained through horizontal and temporal interpolations, the two fields can be quite different (see Figures 26, 27, 28, and 33). The feature model built in OTIS constructs a temperature field according to the bogus information primarily. The SST also reflects the Gulf Stream meanders and warm/cold rings. The input XBT surface temperature is not always the same as the SST at XBT's location because OTIS does internal cyclostrophic adjustment.

Usually, it is quite easy to identify the Sargasso water area to the west of 50°W. The boundary between the Slope water area and the Shelf water area is not clear on the SST field. The Shelf water to the south of Cape Hatteras sometimes reaches a pretty high temperature. It may be due to the southward extrapolation of the Slope water mass properties. In one case, 14 July 1987, the SST off the U.S. southeast coast was higher than that at the axis of the Gulf Stream. This could be real, but caution is needed when OTIS SST is used.

Figures 42 -- 57 show the OTIS analyses of temperature (in degree C) and salinity (in ppt) at 50 m (level 9), 200 m (level 15), 500 m (level 18), and 2,000 m (level 30) depths for each case date. The temperature field is presented with color-coded pixels and salinity is presented with contours. The fields at 50 m level show the properties in the mixed layer. In the Sargasso water area, the gradient of salinity is very weak. Some very cold water (slightly below 0° C) can be found in the Labrador area in spring. At a 200 m level, the salinity gradient is very strong across the Gulf Stream but the temperature gradient is slightly weaker than at the 50 m level. The "Subsurface North Wall" is usually defined as the 15° C isotherm at the 200 m level. Cornillon and Watts

(1987) compared the subjectively-determined Surface North Wall (given in bogus maps) with the Subsurface North Wall and found that the Surface North Wall was, on average, offset 9 km shoreward with a root-mean-square variability of 14.3 km. At the 500 m level, the temperature in the Sargasso water area and in the Slope water area is quite uniform. But, there is a clear jump from Slope water temperature to Sargasso water temperature. Salinity gradient is concentrated at the Gulf Stream front. The 12° C isotherm at the 500 m level is usually used as the "Subsurface Axis" of the Gulf Stream. It is well correlated with the maximum velocity axis. Submerged cold rings usually stand out at 200 m and 500 m levels through salinity change. The 2,000 m level is used as the level-of-no-motion in OTIS. Both the temperature and salinity fields are very uniform. However, the Gulf Stream and warm/cold rings can still be recognized by a very tiny change of salinity. The same color code is used for all temperature fields at 50 m, 200 m, 500 m, and 2,000 m levels. This facilitates the comparisons between levels. However, the contour intervals for salinity fields are adjusted in the vertical to reflect the change of the magnitude of variation.

2. Sea surface dynamic height

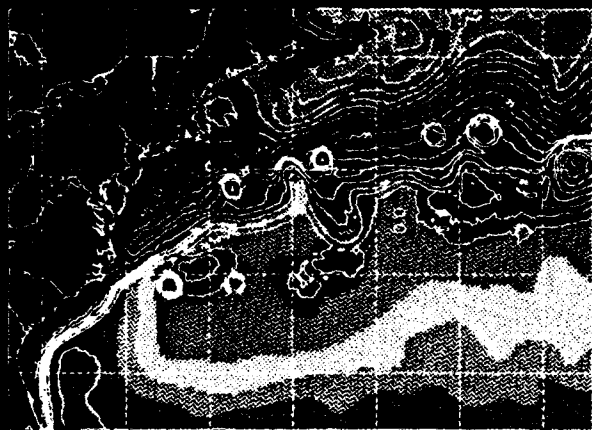
OTIS calculates sea surface dynamic height after the vertical profiles of temperature and salinity are obtained. The reference level (level of no motion) is set at the 2,000 m depth. This value is given to every OTIS grid point and forms a 2-D field. The field is used in the initialization of the NRL layer model. Since much of the continental shelf is less than 2,000 m deep, the sea surface dynamic height obtained this way is not reliable there. Another version of OTIS is used by NRL to correct the problem. No sea surface dynamic height fields are presented in this report.

A better source for sea surface height is the GEOSAT altimetry data. The ERM (exactly repeated measurement) data give reasonable coverage for the Gulf Stream area every 17 days. OI is usually used to generate a 2-D field from data along a set of ascending and descending arcs.

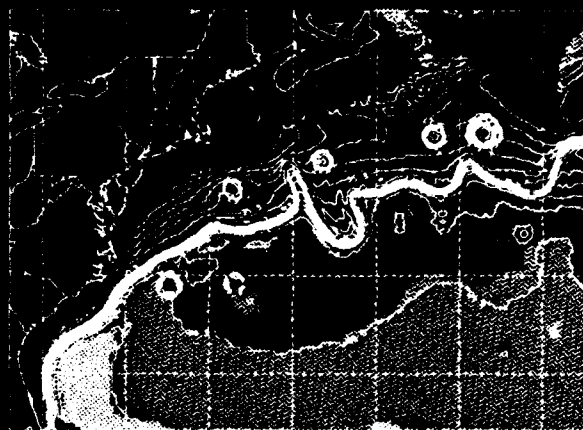
OTIS3 Temperature (C) and Salinity (ppt) 88/05/04

50 m

200 m



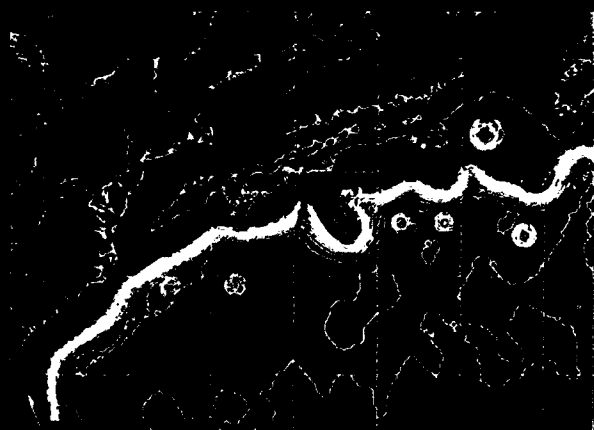
CONTOUR FROM 34 TO 36.5 BY .2



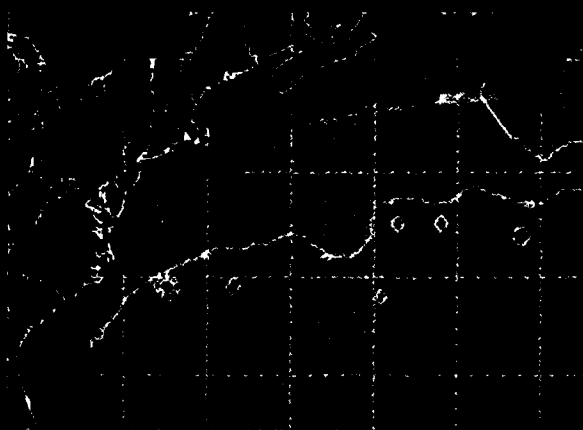
CONTOUR FROM 34.5 TO 36.6 BY .1

500 m

2000 m



CONTOUR FROM 34 TO 36.5 BY .2



CONTOUR FROM 34 TO 36.5 BY .2



2

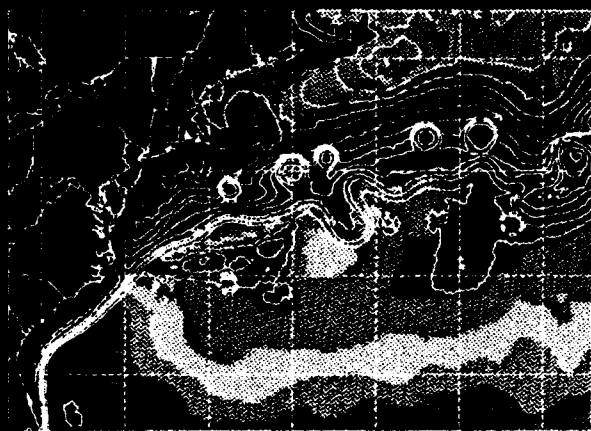
32

Figure 42. OTIS3 temperature and salinity at 50 m, 200 m, 500 m, and 2,000 m levels for 4 May 1988.

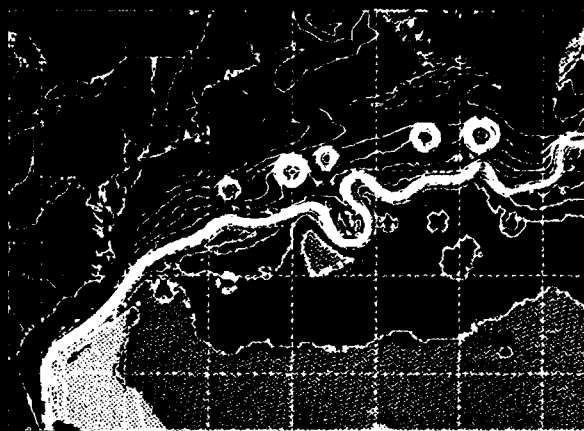
OTIS3 Temperature (C) and Salinity (ppt) 88/05/11

50 m

200 m



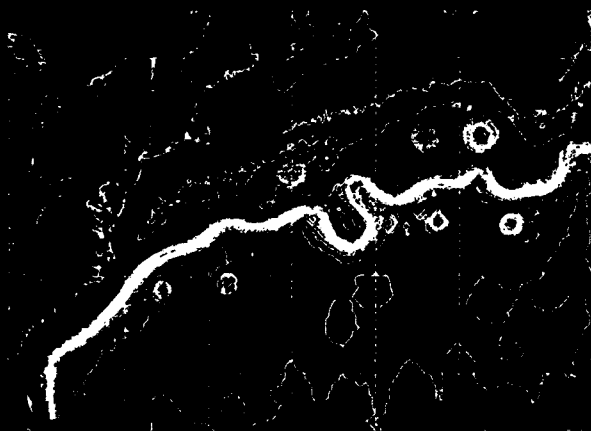
CONTOUR FROM 35.8 TO 36.5 BY .2



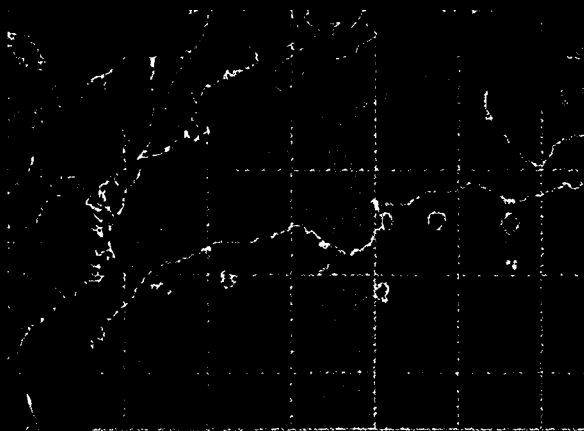
CONTOUR FROM 34.7 TO 36.0 BY .1

500 m

2000 m



CONTOUR FROM 34.0 TO 35.0 BY .2



CONTOUR FROM 34.0 TO 35.0 BY .2



32

36

Figure 43. OTIS3 temperature and salinity at 50 m, 200 m, 500 m, and 2,000 m levels for 11 May 1988.

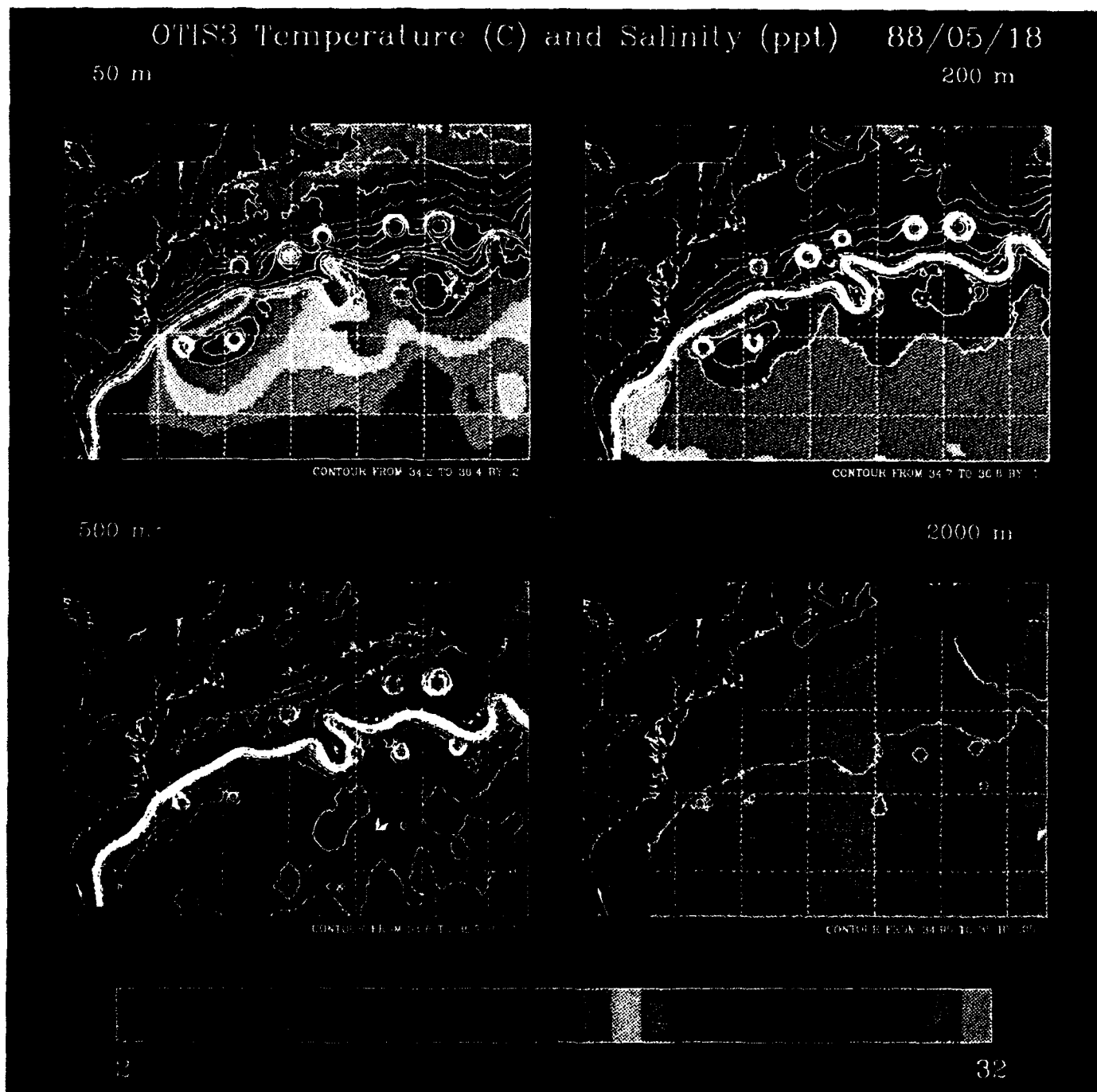
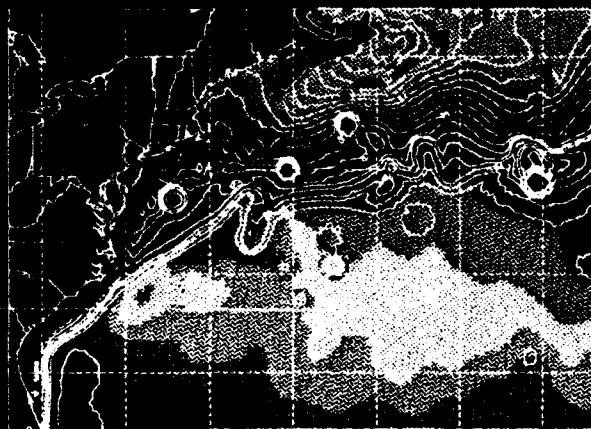


Figure 44. OTIS3 temperature and salinity at 50 m, 200 m, 500 m, and 2,000 m levels for 18 May 1988.

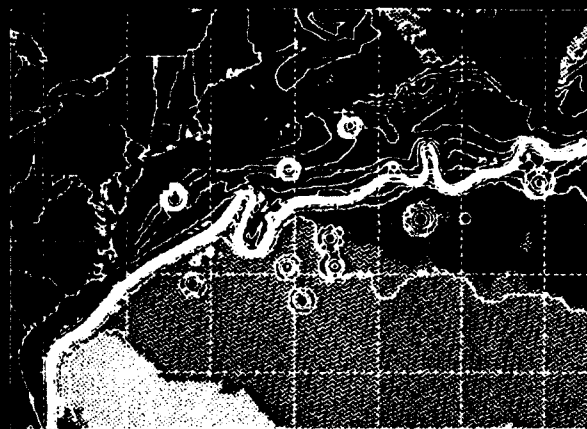
OTIS3 Temperature (C) and Salinity (ppt) 87/05/06

50 m

200 m



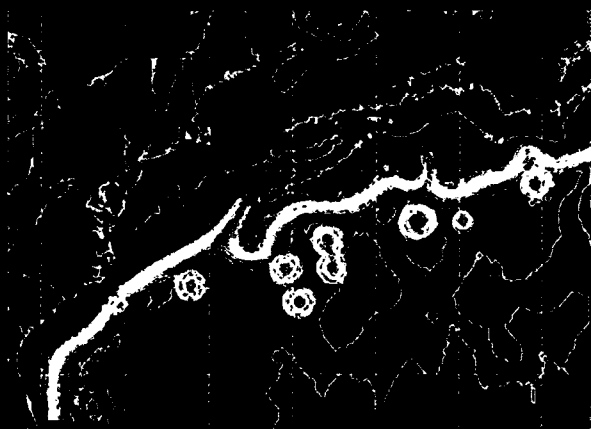
CONTOUR FROM 32.5 TO 36.6 BY 2



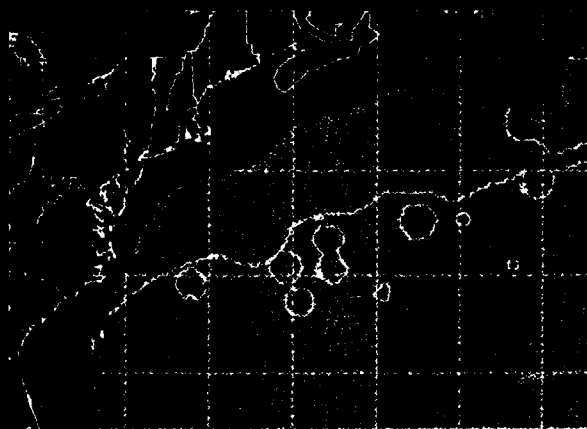
CONTOUR FROM 34.5 TO 36.6 BY 1

500 m

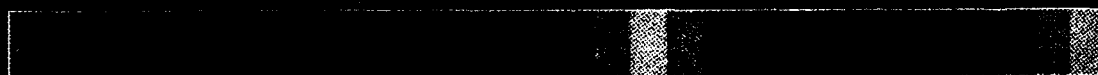
2000 m



CONTOUR FROM 34.6 TO 36.6 BY 1



CONTOUR FROM 34.8 TO 36 BY 0.2



2

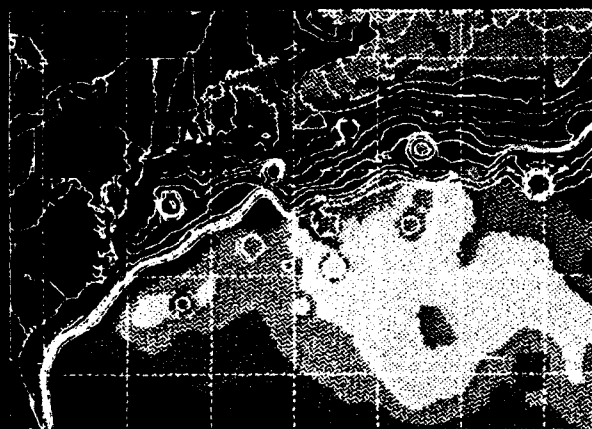
32

Figure 45. OTIS3 temperature and salinity at 50 m, 200 m, 500 m, and 2,000 m levels for 6 May 1987.

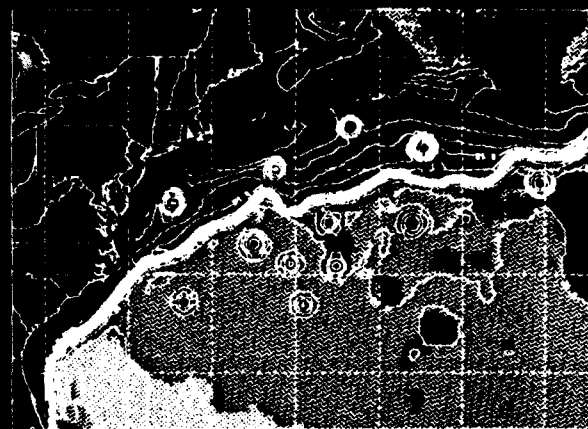
OTIS3 Temperature (C) and Salinity (ppt) 87/05/13

50 m

200 m



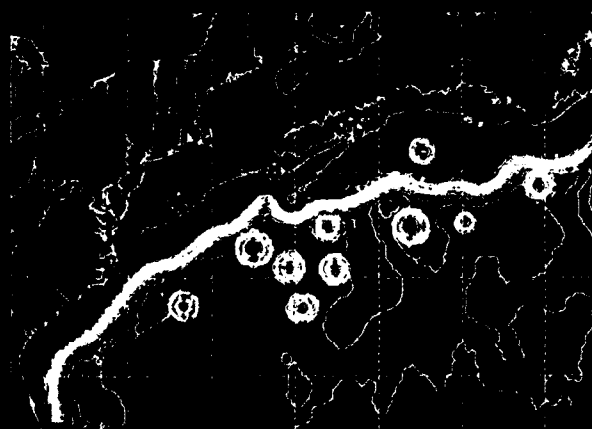
CONTOUR FROM 34 TO 36.4 BY .2



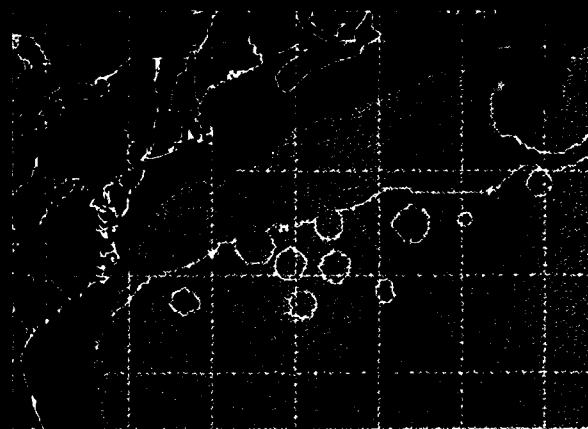
CONTOUR FROM 34.5 TO 36.6 BY .1

500 m

2000 m



CONTOUR FROM 32.6 TO 36.1 BY .1



CONTOUR FROM 34.0 TO 35.0 BY .05



2

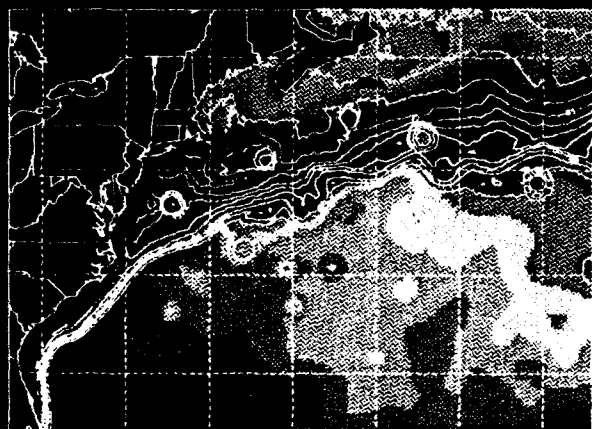
32

Figure 46. OTIS3 temperature and salinity at 50 m, 200 m, 500 m, and 2,000 m levels for 13 May 1987.

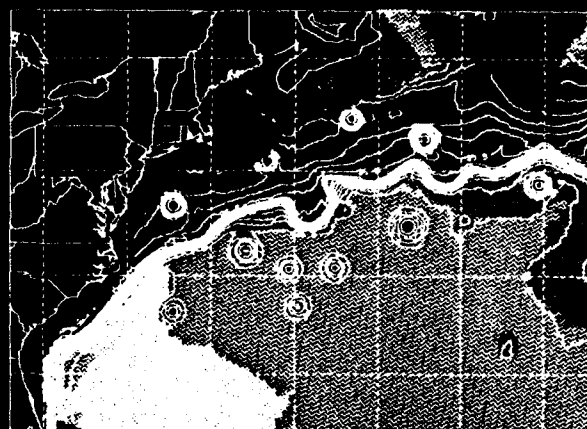
OTIS3 Temperature (C) and Salinity (ppt) 87/05/20

50 m

200 m



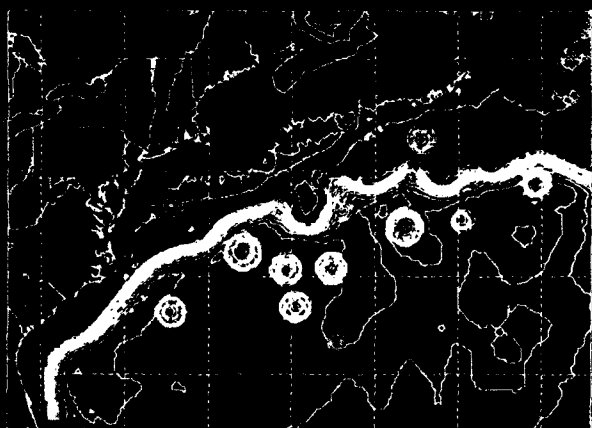
CONTOUR FROM 34.2 TO 36.4 BY .2



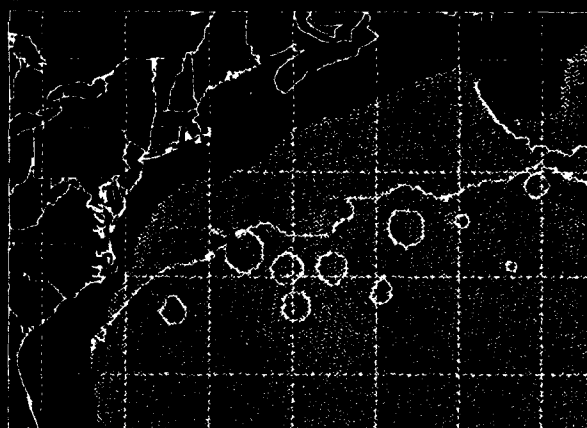
CONTOUR FROM 34.8 TO 36.6 BY .1

500 m

2000 m



CONTOUR FROM 34.8 TO 36.5 BY .1



CONTOUR FROM 34.85 TO 35 BY .05



2

32

Figure 47. OTIS3 temperature and salinity at 50 m, 200 m, 500 m, and 2,000 m levels for 20 May 1987.

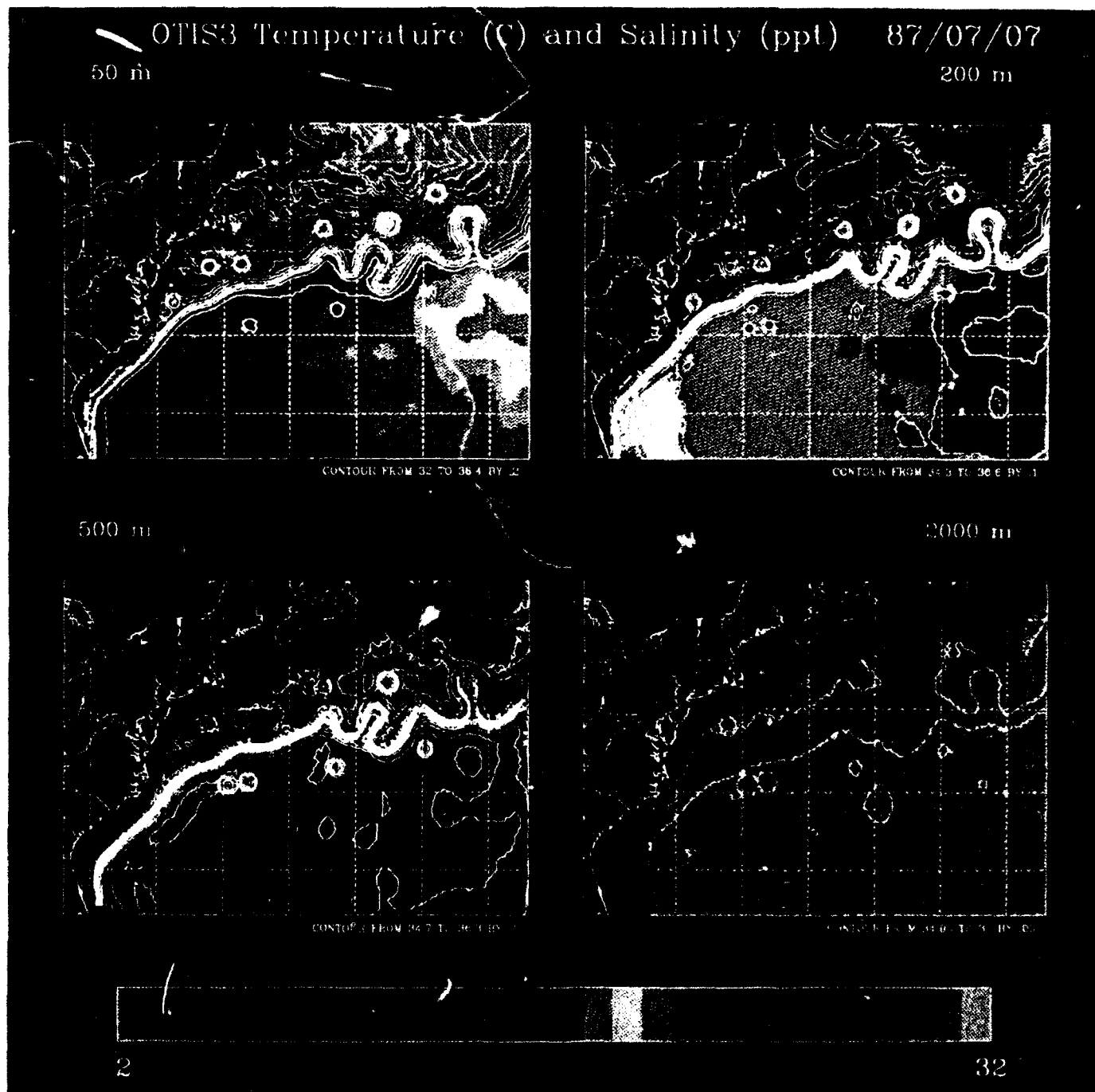
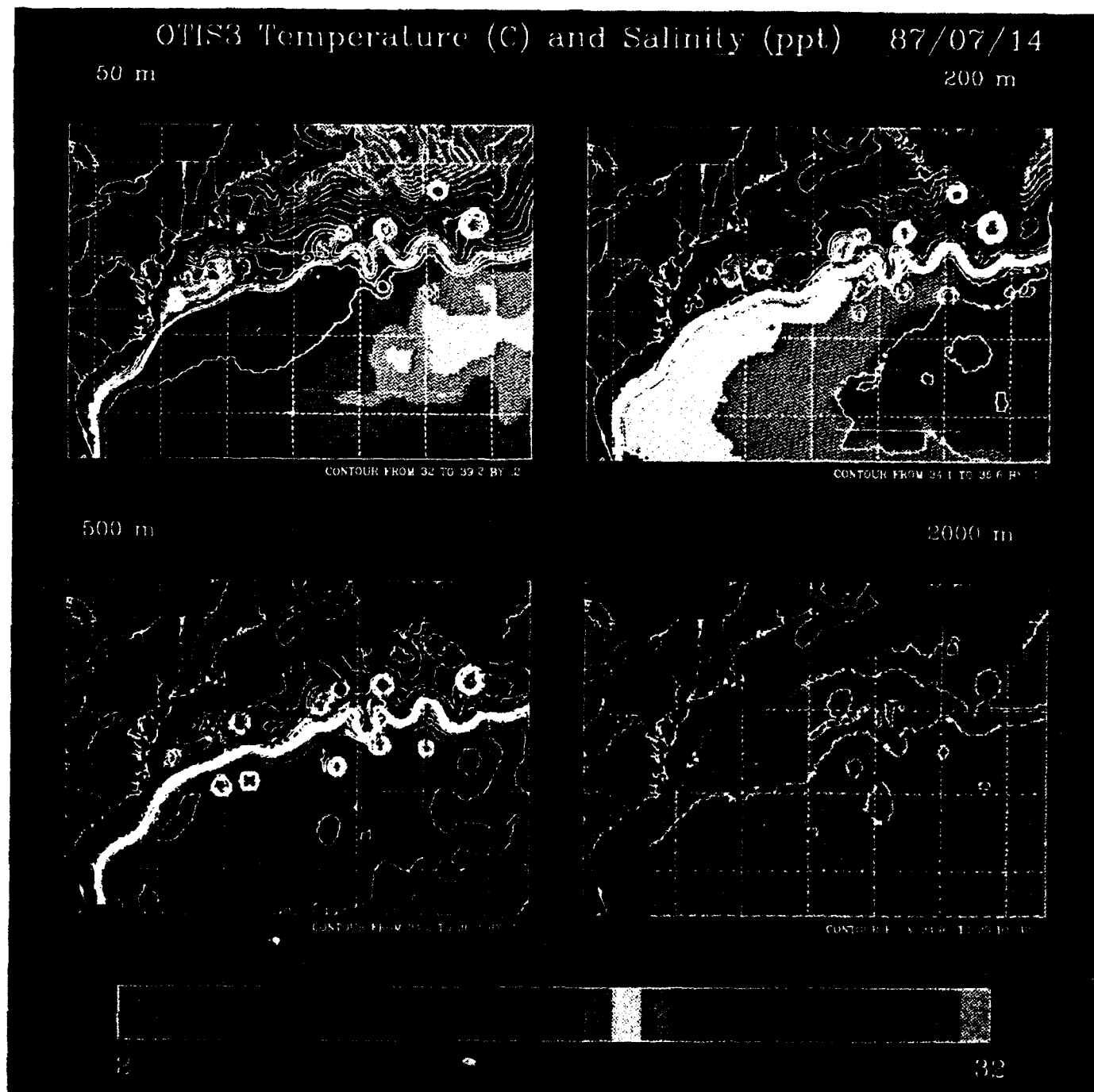


Figure 46. OTIS3 temperature and salinity at 50 m, 200 m, 500 m, and 2,000 m levels for 7 July 1987.



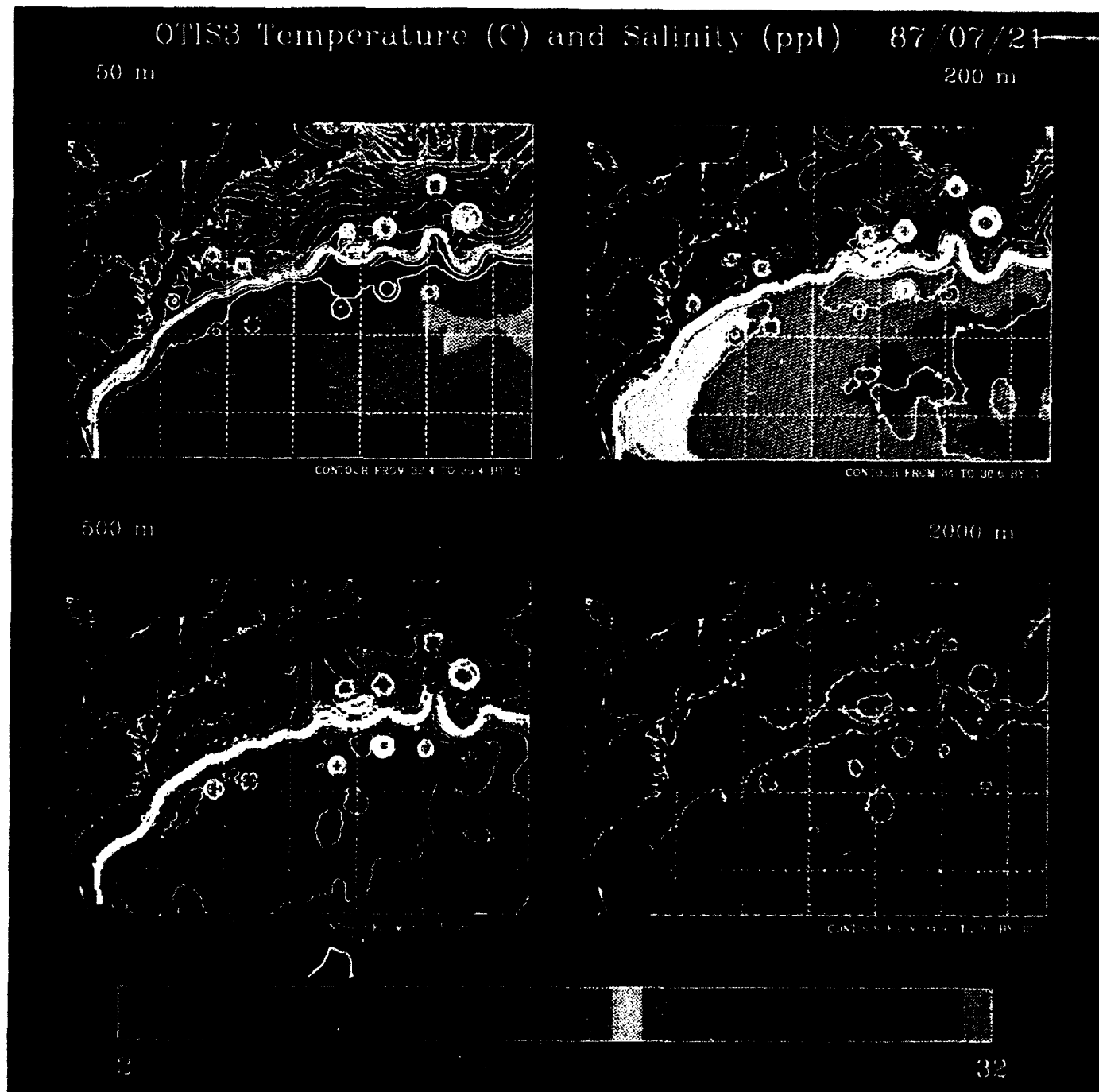
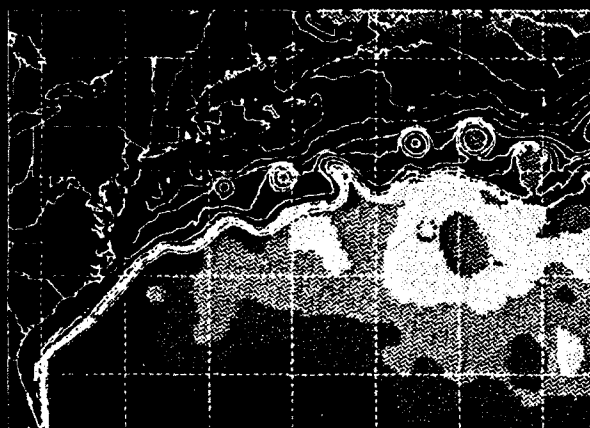


Figure 50. OTIS3 temperature and salinity at 50 m, 200 m, 500 m, and 2,000 m levels for 21 July 1987.

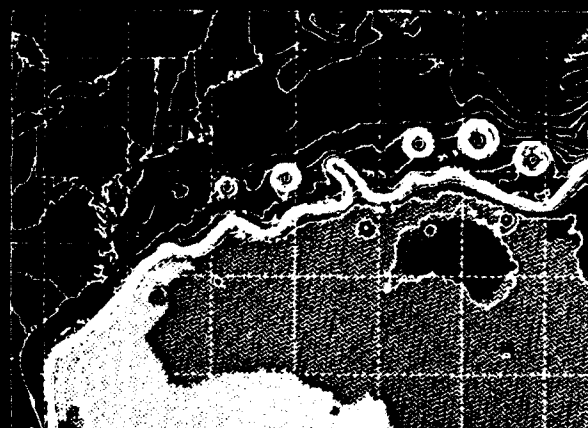
OTIS3 Temperature (C) and Salinity (ppt) 88/05/25

50 m

200 m



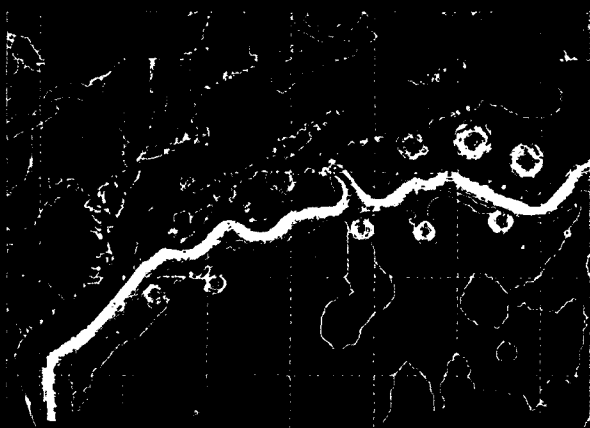
CONTOUR FROM 34.3 TO 36.4 BY .2



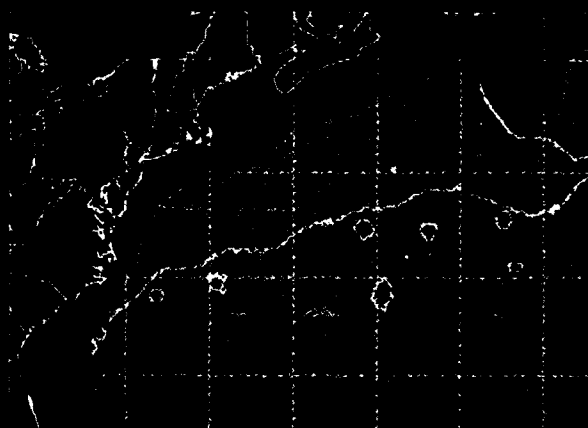
CONTOUR FROM 34.5 TO 36.6 BY .2

500 m

2000 m



CONTOUR FROM 34.7 TO 36.8 BY .2



CONTOUR FROM 34.9 TO 36.9 BY .2



2

32

Figure 51. OTIS3 temperature and salinity at 50 m, 200 m, 500 m, and 2,000 m levels for 25 May 1988.

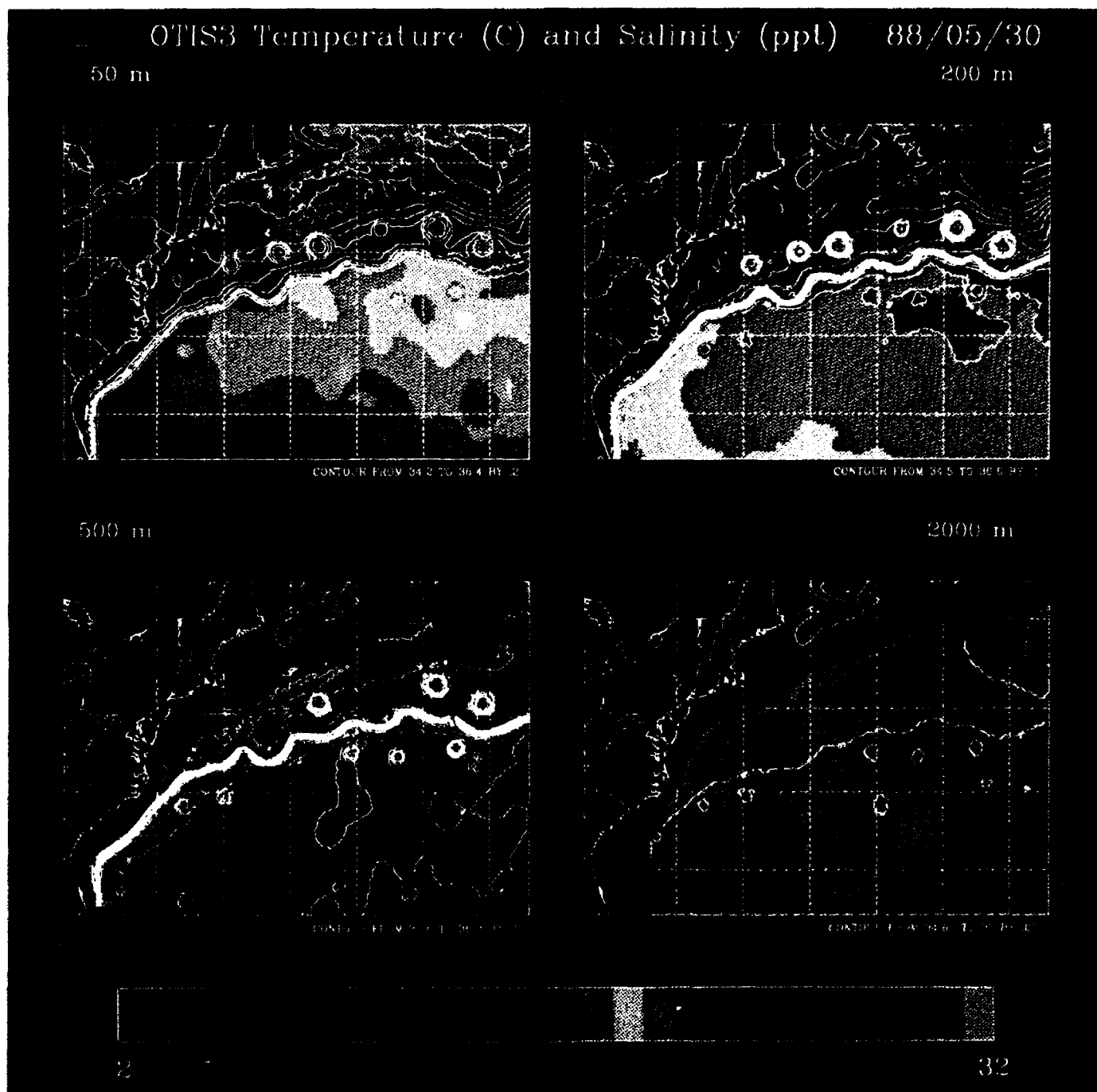
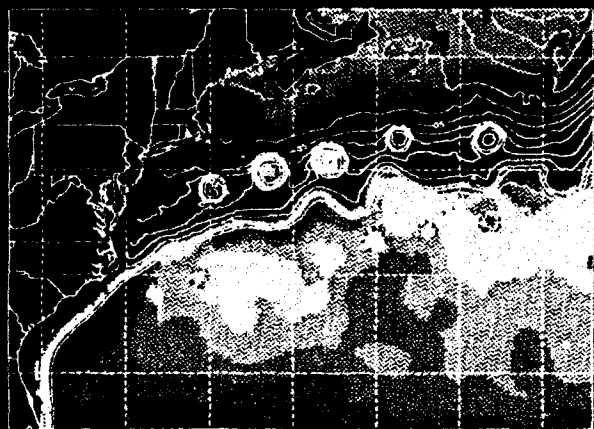


Figure 52. OTIS3 temperature and salinity at 50 m, 200 m, 500 m, and 2,000 m levels for 30 May 1988.

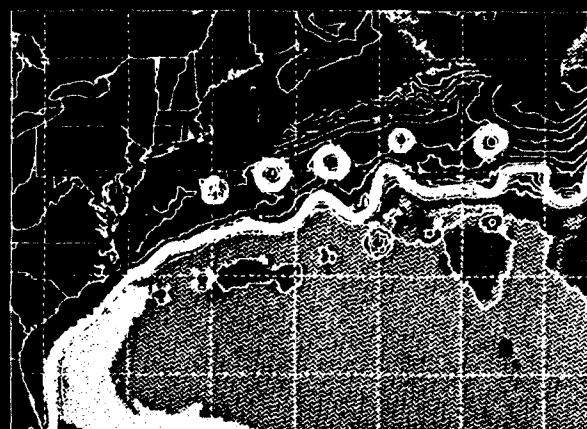
OTIS3 Temperature (C) and Salinity (ppt) 88/06/13

50 m

200 m



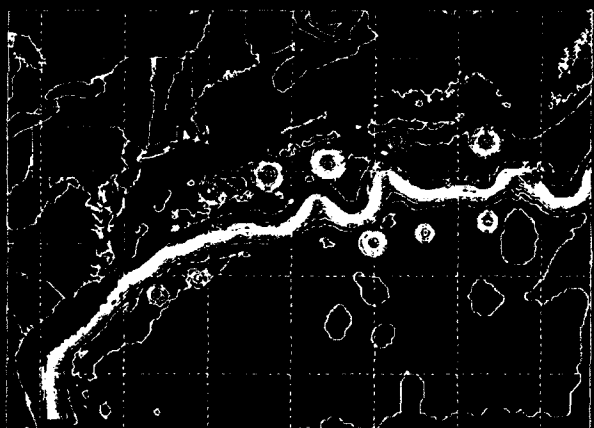
CONTOUR FROM 33.8 TO 30.4 BY .2



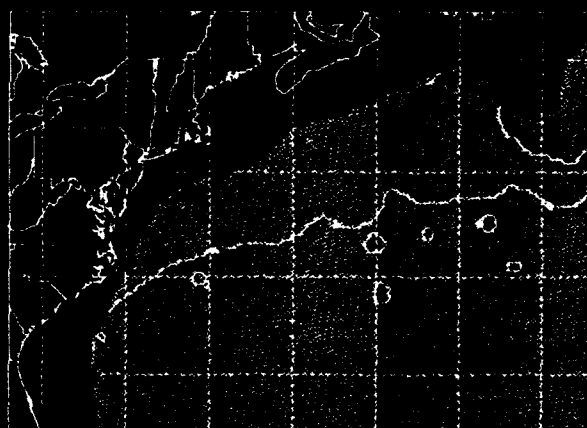
CONTOUR FROM 34.7 TO 30.6 BY .1

500 m

2000 m



CONTOUR FROM 34.8 TO 30.4 BY .1



CONTOUR FROM 34.05 TO 30 BY .05



2

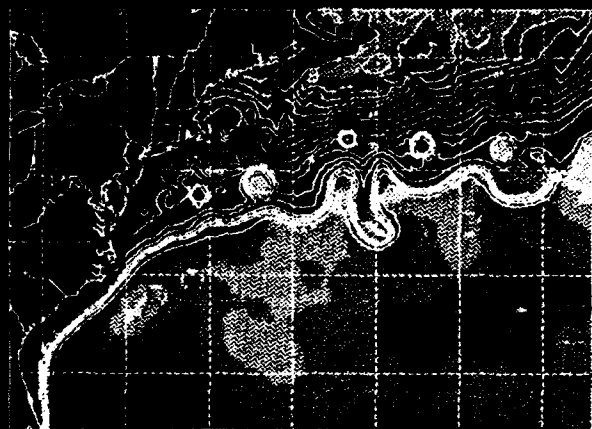
32

Figure 54. OTIS3 temperature and salinity at 50 m, 200 m, 500 m, and 2,000 m levels for 13 June 1988.

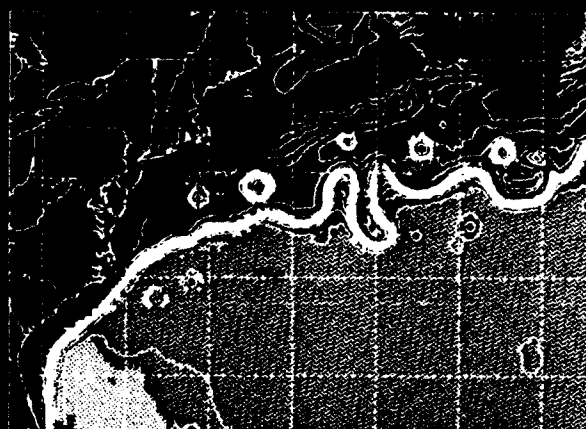
OTIS3 Temperature (C) and Salinity (ppt) 88/06/29

50 m

200 m



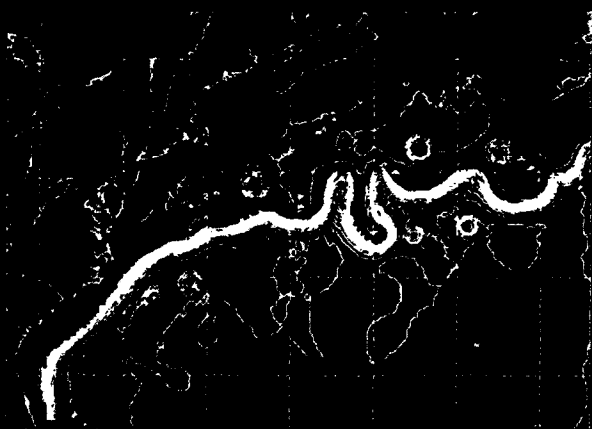
CONTOUR FROM 32.5 TO 36.4 BY .2



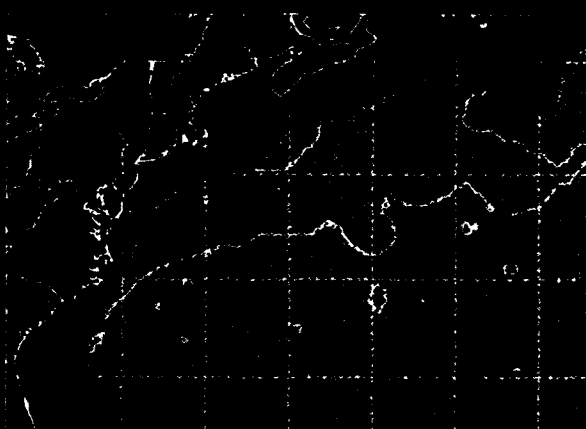
CONTOUR FROM 34.5 TO 36.6 BY .1

500 m

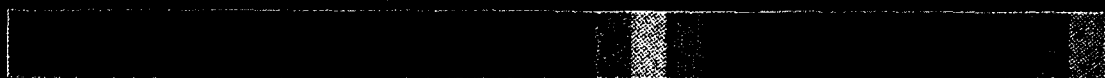
2000 m



CONTOUR FROM 32.5 TO 36.4 BY .2



CONTOUR FROM 34.5 TO 36.6 BY .1



2

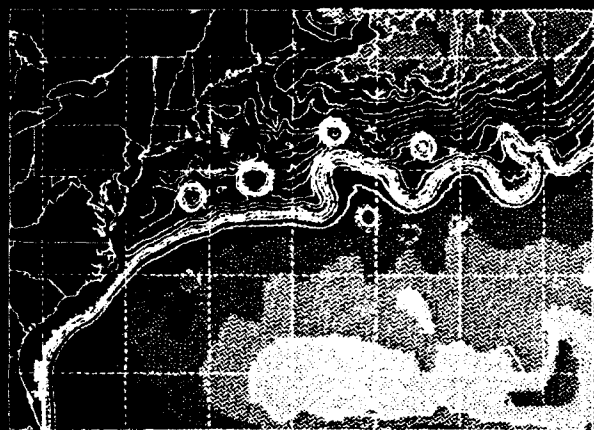
32

Figure 56. OTIS3 temperature and salinity at 50 m, 200 m, 500 m, and 2,000 m levels for 29 June 1988.

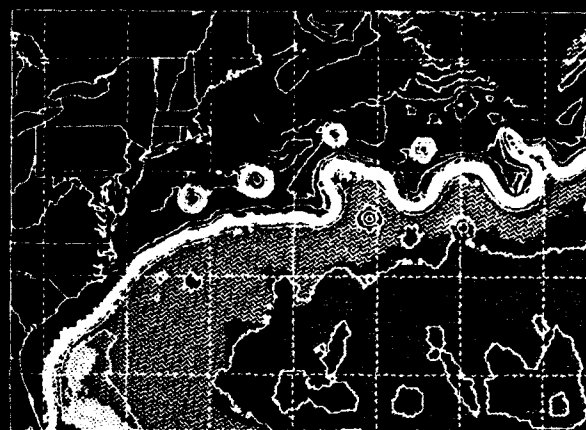
OTIS3 Temperature (C) and Salinity (ppt) 88/07/04

50 m

200 m



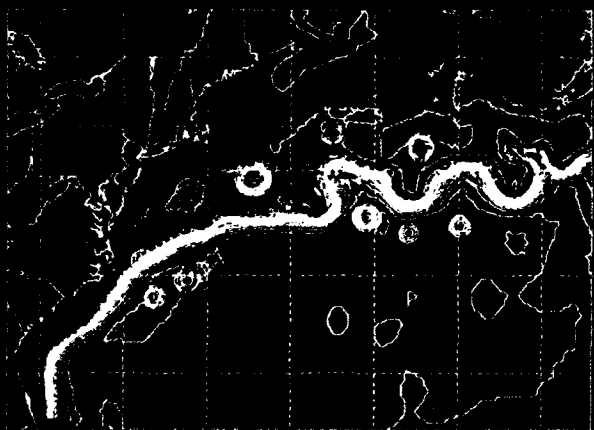
CONTOUR FROM 32.2 TO 38.4 BY .2



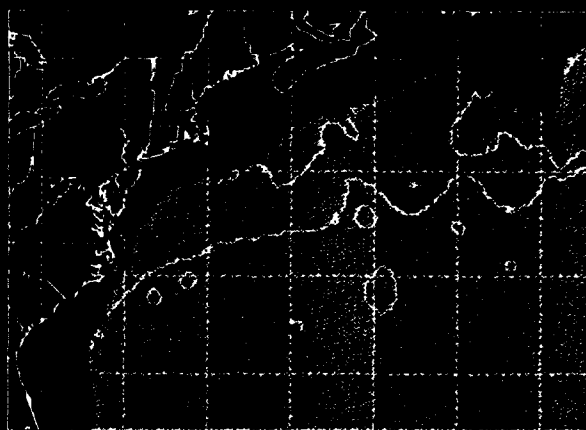
CONTOUR FROM 34.4 TO 36.6 BY .1

500 m

2000 m



CONTOUR FROM 24.4 TO 30.6 BY .2



CONTOUR FROM 34.85 TO 35 BY .05



2

32

Figure 57. OTIS3 temperature and salinity at 50 m, 200 m, 500 m, and 2,000 m levels for 4 July 1988.

IV. Hierarchy of DAMEE Data Directory

All DAMEE data files have been archived in a directory residing in the COAM/USM optical storage device "epoch". The path name of the directory is: /epoch/data2/cal/DAMEE. Under this directory, there are several levels of subdirectories. When accessing files, one should always read the README file in each level of the directory. Table 3 is the "directory-tree" of DAMEE data. The name of a subdirectory always ends with a "/". The others are data file names. Two conventions have been used to give the date of a data file. The first one is ".yydddv", where yy is the year, ddd is the year day, and v is the version. The other one is ".yymmdd", where yy is the year, mm is the month, and dd is the day.

Table 3. DAMEE Data Directory-Tree

README

assm/

navo-bt/

README

nv87011a.dat	nv87011a.hdr	nv87011b.dat	nv87011b.hdr
nv87014a.dat	nv87014a.hdr	nv87015a.dat	nv87015a.hdr
nv87017a.dat	nv87017a.hdr	nv87126a.dat	nv87126a.hdr
nv87126b.dat	nv87126b.hdr	nv87129a.dat	nv87129a.hdr
nv87129b.dat	nv87129b.hdr	nv87130a.dat	nv87130a.hdr
nv87130b.dat	nv87130b.hdr	nv87144a.dat	nv87144a.hdr
nv87144b.dat	nv87144b.hdr	nv87146a.dat	nv87146a.hdr
nv87146b.dat	nv87146b.hdr	nv87147a.dat	nv87147a.hdr
nv87147b.dat	nv87147b.hdr	nv88011a.dat	nv88011a.hdr
nv88012a.dat	nv88012a.hdr	nv88012b.dat	nv88012b.hdr
nv88017a.dat	nv88017a.hdr	nv88017b.dat	nv88017b.hdr
nv88019a.dat	nv88019a.hdr	nv88020a.dat	nv88020a.hdr
nv88020b.dat	nv88020b.hdr	nv88022a.dat	nv88022a.hdr
nv88022b.dat	nv88022b.hdr	nv88161b.dat	nv88161b.hdr
nv88164a.dat	nv88164a.hdr	nv88164b.dat	nv88164b.hdr
nv88167a.dat	nv88167a.hdr	nv88167b.dat	nv88167b.hdr
nv88169a.dat	nv88169a.hdr	nv88169b.dat	nv88169b.hdr
nv88171a.dat	nv88171a.hdr	nv88171b.dat	nv88171b.hdr
nv88173a.dat	nv88173a.hdr	nv88173b.dat	nv88173b.hdr
nv88175a.dat	nv88175a.hdr	nv88309a.dat	nv88309a.hdr
nv88311a.dat	nv88311a.hdr	nv88311b.dat	nv88311b.hdr
nv88313a.dat	nv88313a.hdr	nv88318a.dat	nv88318a.hdr
nv88318b.dat	nv88318b.hdr	nv88320a.dat	nv88320a.hdr

nv88320b.dat nv88320b.hdr nv88323b.dat nv88323b.hdr
 nv88325a.dat nv88325a.hdr nv89142a.dat nv89142a.hdr
 nv89145a.dat nv89145a.hdr nv89145b.dat nv89145b.hdr
 nv89147a.dat nv89147a.hdr nv89149a.dat nv89149a.hdr
 nv89153a.dat nv89153a.hdr nv89156b.dat nv89156b.hdr

nodc-bt/

README

err/

nodc_err.f

ibt/

ibt8890.7109 ibt8890.7204 ibt8890.7205 ibt8890.7206
 ibt8890.7207 ibt8890.7208 ibt8890.7209 ibt8890.7304
 ibt8890.7305 ibt8890.7306 ibt8890.7307 ibt8890.7308
 ibt8890.7404 ibt8890.7405 ibt8890.7406 ibt8890.7407

sbt/

sbt8890.7204 sbt8890.7205 sbt8890.7206 sbt8890.7208
 sbt8890.7209 sbt8890.7304 sbt8890.7305 sbt8890.7306
 sbt8890.7307 sbt8890.7308 sbt8890.7404 sbt8890.7405

sd2/

new/

sd28890.7209.hdr sd28890.7209.new
 sd28890.7305.hdr sd28890.7305.new
 sd28890.7306.hdr sd28890.7306.new
 sd28890.7307.hdr sd28890.7307.new
 sd28890.7405.hdr sd28890.7405.new
 sd28890.7406.hdr sd28890.7406.new
 sd28890.7407.hdr sd28890.7407.new

old/

sd28890.7209 sd28890.7209.hdr
 sd28890.7305 sd28890.7305.hdr
 sd28890.7306 sd28890.7306.hdr
 sd28890.7307 sd28890.7307.hdr
 sd28890.7404 sd28890.7404.hdr
 sd28890.7405 sd28890.7405.hdr
 sd28890.7406 sd28890.7406.hdr
 sd28890.7407 sd28890.7407.hdr

std/

new/

std8890.7206.hdr std8890.7206.new
 std8890.7207.hdr std8890.7207.new
 std8890.7208.hdr std8890.7208.new
 std8890.7209.hdr std8890.7209.new
 std8890.7306.hdr std8890.7306.new
 std8890.7307.hdr std8890.7307.new
 std8890.7308.hdr std8890.7308.new
 std8890.7404.hdr std8890.7404.new
 std8890.7406.hdr std8890.7406.new
 std8890.7407.hdr std8890.7407.new

old/

std8890.7206 std8890.7206.hdr
std8890.7207 std8890.7207.hdr
std8890.7208 std8890.7208.hdr
std8890.7209 std8890.7209.hdr
std8890.7306 std8890.7306.hdr
std8890.7307 std8890.7307.hdr
std8890.7308 std8890.7308.hdr
std8890.7404 std8890.7404.hdr
std8890.7406 std8890.7406.hdr
std8890.7407 std8890.7407.hdr

xbt/

xbt8890.7109 xbt8890.7204 xbt8890.7205 xbt8890.7206
xbt8890.7207 xbt8890.7208 xbt8890.7209 xbt8890.7304
xbt8890.7305 xbt8890.7306 xbt8890.7307 xbt8890.7308
xbt8890.7404 xbt8890.7405 xbt8890.7406 xbt8890.7407

otis-input/

README
gdem/

mcsst/

sst.870506 sst.870513 sst.870520 sst.870707
sst.870714 sst.870721 sst.880504 sst.880511
sst.880518 sst.880530 sst.880601 sst.880605
sst.880613 sst.880622 sst.880629 sst.880704

stream/

README
bogmsg/

README
final/

bogmsg.870506 bogmsg.870513 bogmsg.870520
bogmsg.870707 bogmsg.870714 bogmsg.870721
bogmsg.880504 bogmsg.880511 bogmsg.880518
bogmsg.880525 bogmsg.880530 bogmsg.880605
bogmsg.880613 bogmsg.880622 bogmsg.880629
bogmsg.880704

shift-15/

bogmsg.870506 bogmsg.870513 bogmsg.870520
bogmsg.870707 bogmsg.870714 bogmsg.870721
bogmsg.880504 bogmsg.880511 bogmsg.880518
bogmsg.880530 bogmsg.880605 bogmsg.880613
bogmsg.880622 bogmsg.880629 bogmsg.880704

data/

README
jul87/

ocnbog.870707 ocnbog.870714 ocnbog.870721
ocnbog.87188 ocnbog.87195 ocnbog.87202
rg_data.87188d rg_data.87195d rg_data.87202d

jun88/

gs_nwall.88151 gs_nwall.88157 gs_nwall.88165
gs_nwall.88174 gs_nwall.88181 gs_nwall.88186
gs_rings.88151 gs_rings.88157 gs_rings.88165
gs_rings.88174 gs_rings.88181 gs_rings.88186
rg_data.88151 rg_data.88157 rg_data.88165
rg_data.88174 rg_data.88181 rg_data.88186

may87/

ocnbog.870506 ocnbog.870513 ocnbog.870520
ocnbog.87126 ocnbog.87133 ocnbog.87140
rg_data.87126d rg_data.87133d rg_data.87140d

bogmsg.880504 bogmsg.880511 bogmsg.880518
bogmsg.88125 bogmsg.88132 bogmsg.88139
ocnbog.880504 ocnbog.880511 ocnbog.880518
ocnbog.88125 ocnbog.88132 ocnbog.88139
rg_data.88125e rg_data.88132e rg_data.88139e

ocnbog/

ocnbog.870506 ocnbog.870513 ocnbog.870520
ocnbog.870707 ocnbog.870714 ocnbog.870721
ocnbog.880504 ocnbog.880511 ocnbog.880518
ocnbog.880530 ocnbog.880605 ocnbog.880613
ocnbog.880622 ocnbog.880629 ocnbog.880704
ocnbog.88151 ocnbog.88157 ocnbog.88165
ocnbog.88174 ocnbog.88181 ocnbog.88186

xbt/

README xbt.87 xbt.88 xbt.8805

otis-output/

README

format.out

otis-final/

ot.870506 ot.870513 ot.870520 ot.870707
ot.870714 ot.870721 ot.880504 ot.880511
ot.880518 ot.880525 ot.880530 ot.880605
ot.880613 ot.880622 ot.880629 ot.880704

zdepth

Most of the subdirectory and file names used in the directory are abbreviations of common oceanography terms mentioned in earlier sections. The word "assm" stands for assimilation, "ocnbog" stands for "ocean bogus", "bogmsg" stands for "bogus message", "rg_data" stands for "ring data", and "ot" stands for "OTIS analysis".

The following are a few sample pieces of data:

- (1) Sample data of bogus information (including Gulf Stream Surface North Wall and warm and cold rings) for 14 July 1987:

1021000000000011	00		FRONT	*****ORIGINAL*****		U
1021000000000021	87071400	87071400		437		U
1021000000000031	24.57	-80.89100 20	24.63	-80.80100 20	24.70 -80.71100 20	U
1021000000000041	24.77	-80.61100 20	24.84	-80.51100 20	24.90 -80.43100 20	U
1021000000000051	24.98	-80.35100 20	25.10	-80.28100 20	25.29 -80.21100 20	U
1021000000000061	25.58	-80.14100 20	25.95	-80.08100 20	26.36 -80.03100 20	U
1021000000000071	26.78	-79.99100 20	27.17	-79.98100 20	27.53 -79.99100 20	U
1021000000000081	27.87	-80.01100 20	28.23	-80.05100 20	28.61 -80.09100 20	U
1021000000000091	29.01	-80.14100 20	29.42	-80.16100 20	29.80 -80.16100 20	U
1021000000000101	30.14	-80.12100 20	30.42	-80.05100 20	30.65 -79.94100 20	U
:						
1021000000001451	40.59	-46.84100 20	40.63	-46.75100 20	40.66 -46.67100 20	U
1021000000001461	40.69	-46.58100 20	40.73	-46.49100 20	40.76 -46.40100 20	U
1021000000001471	40.80	-46.32100 20	40.83	-46.23100 20	40.87 -46.14100 20	U
1021000000001481	40.90	-46.06100 20	40.94	-45.97100 20		U
3021187010000011	00		EDDY CENTER	****ORIGINAL****		U
3021187010000021	87071400	87071400	10	25.0 060100		U
3021187010000031	37.00	-74.00100 000100	052100	052100		U
3021187020000011	00		EDDY CENTER	****ORIGINAL****		U
3021187020000021	87071400	87071400	10	25.0 060100		U
3021187020000031	39.70	-71.10100 000100	052100	052100		U
3021187030000011	00		EDDY CENTER	****ORIGINAL****		U
3021187030000021	87071400	87071400	10	24.0 060100		U
3021187030000031	39.10	-68.80100 000100	052100	052100		U
3021187040000011	00		EDDY CENTER	****ORIGINAL****		U
3021187040000021	87071400	87071400	10	24.5 060100		U
3021187040000031	41.04	-61.29100 000100	052100	052100		U
3021187050000011	00		EDDY CENTER	****ORIGINAL****		U
3021187050000021	87071400	87071400	10	24.0 060100		U
3021187050000031	41.30	-58.10100 000100	065100	065100		U
3021187060000011	00		EDDY CENTER	****ORIGINAL****		U
3021187060000021	87071400	87071400	10	17.0 060100		U
3021187060000031	43.47	-54.19100 000100	048100	048100		U
3021187070000011	00		EDDY CENTER	****ORIGINAL****		U
3021187070000021	87071400	87071400	10	23.5 060100		U
3021187070000031	41.56	-51.43100 000100	078100	078100		U
3021287080000011	00		EDDY CENTER	****ORIGINAL****		U
3021287080000021	87071400	87071400	10	27.5 060100		U
3021287080000031	35.25	-70.20100 000100	052100	052100		U
3021287090000011	00		EDDY CENTER	****ORIGINAL****		U
3021287090000021	87071400	87071400	10	24.5 060100		U
3021287090000031	35.60	-68.10100 000100	052100	052100		U
3021287100000011	00		EDDY CENTER	****ORIGINAL****		U
3021287100000021	87071400	87071400	10	23.5 060100		U
3021287100000031	36.52	-61.50100 000100	052100	052100		U
3021287110000011	00		EDDY CENTER	****ORIGINAL****		U

```

3021287110000021 87071400 87071400    10 22.0 060100
3021287110000031 37.60 -54.80100 000100 052100 052100
3021287120000011 00                      EDDY CENTER ****ORIGINAL****
3021287120000021 87071400 87071400    10 23.0 060100
3021287120000031 37.96 -58.30100 000100 065100 065100

```

U
U
U
U
U

(2) Sample XBT data for 28 April 1988:

```

8804280000 33.90 -67.22      8
  0.0 18.89 61.0 18.89 305.0 17.78 390.0 17.22
8804280000 34.32 -67.42      8
  0.0 19.00 31.0 18.94 244.0 18.33 366.0 17.50
8804280000 36.97 -67.28     10
  0.0 20.83 31.0 20.83 46.0 18.89 274.0 18.72 396.0 18.06
8804280000 38.43 -67.43     14
  0.0 13.89 31.0 13.89 91.0 11.67 122.0 12.22 244.0 8.33 274.0 6.67 396.0 6.11
8804280000 39.15 -67.48     12
  0.0 13.56 15.0 13.22 91.0 14.44 98.0 13.33 213.0 11.11 305.0 7.94
8804280000 39.55 -67.53     10
  0.0 17.83 213.0 17.78 250.0 17.50 274.0 15.56 320.0 14.17
8804280000 40.02 -64.38     20
  0.0 17.78 31.0 18.33 61.0 17.78 91.0 14.44 122.0 15.83 198.0 14.44 213.0 13.78 274.0 12.22
366.0 8.89 396.0 8.33

```

(3) Sample MCSST data input to OTIS for 6 May 1987:

```

1 87
050600 2636 -8191 245 050600 2636 -8173 245 050600 2636 -7998 269 050600 2636 -7980 269 050600 2636 -7962 268
050600 2636 -7945 268 050600 2636 -7927 267 050600 2636 -7910 271 050600 2636 -7892 278 050600 2636 -7874 272
050600 2636 -7857 267 050600 2636 -7839 264 050600 2636 -7822 263 050600 2636 -7804 261 050600 2636 -7787 261
050600 2636 -7769 262 050600 2636 -7751 262 050600 2636 -7734 265 050600 2636 -7716 264 050600 2636 -7699 261
050600 2636 -7681 262 050600 2636 -7664 250 050600 2636 -7646 248 050600 2636 -7628 247 050600 2636 -7611 248
050600 2636 -7593 249 050600 2636 -7576 248 050600 2636 -7558 250 050600 2636 -7540 252 050600 2636 -7523 253
050600 2636 -7505 255 050600 2636 -7488 254 050600 2636 -7470 253 050600 2636 -7453 259 050600 2636 -7435 258
050600 2636 -7417 260 050600 2636 -7400 257 050600 2636 -7382 258 050600 2636 -7365 257 050600 2636 -7347 259
050600 2636 -7329 260 050600 2636 -7312 264 050600 2636 -7294 262 050600 2636 -7277 261 050600 2636 -7259 259
050600 2636 -7242 255 050600 2636 -7224 257 050600 2636 -7206 264 050600 2636 -7189 267 050600 2636 -7171 261

```

(4) Sample OTIS analysis for 4 May 1988:

```

0 4 5 88 178 101 -47.0000 -82.0000 27.0000 47.0000
1 1 -82.00 27.00 1.803 10.078
25.47 25.39 25.25 24.97 24.57 23.84 23.10 22.43 21.56 20.77 19.97 18.84 18.23 17.85 16.71 14.46 12.92
11.36 10.70 9.44 8.02 6.75 5.72 4.95 4.45 4.23 4.09 4.02 3.81 3.62 3.15 2.74 2.35 2.34
36.27 36.27 36.28 36.28 36.28 36.29 36.30 36.30 36.31 36.32 36.32 36.31 36.29 36.28 36.19 36.04 35.87
35.62 35.48 35.31 35.18 35.10 35.06 35.04 5.02 35.01 35.00 35.00 35.00 34.99 34.98 34.94 34.90 34.88
-0.20 0.28 0.42 -0.70 -1.09 -1.78 -2.44 -2.93 -3.57 -3.72 -3.88 -3.79 -3.72 -3.70 -3.49 -3.16 -3.30
-3.05 -3.08 -2.58 -1.93 -1.34 -0.86 -0.51 -0.29 -0.21 -0.16 -0.16 -0.17 -0.12 -0.05 0.01 -0.02 -0.03

```

1.20	1.20	1.21	1.24	1.27	1.30	1.30	1.25	1.18	1.14	1.09	1.02	0.98	0.97	0.98	0.98	0.90
0.89	0.89	0.91	0.90	0.89	0.82	0.69	0.59	0.59	0.47	0.45	0.41	0.33	0.34	0.34	0.22	0.20
2	1	-81.80		27.00	1.730	9.228										
25.40	25.31	25.12	24.77	24.27	23.38	22.46	21.69	20.66	19.83	19.00	17.89	17.29	16.93	15.80	13.58	12.08
10.58	9.93	8.79	7.54	6.41	5.50	4.82	4.37	4.17	4.05	3.97	3.77	3.58	3.13	2.74	2.35	2.34
36.21	36.21	36.21	36.21	36.21	36.21	36.21	36.22	36.22	36.21	36.21	36.20	36.17	36.14	36.07	35.93	35.76
35.53	35.39	35.25	35.14	35.08	35.05	35.03	35.02	35.00	35.00	34.99	34.99	34.98	34.98	34.94	34.90	34.88
-0.28	-0.37	-0.55	-0.90	-1.39	-2.25	-3.08	-3.68	-4.48	-4.67	-4.86	-4.74	-4.65	-4.62	-4.36	-3.96	-4.14
-3.84	-3.85	-3.23	-2.41	-1.68	-1.07	-0.64	-0.37	-0.27	-0.20	-0.21	-0.21	-0.16	-0.07	0.01	-0.02	-0.03
1.15	1.16	1.16	1.19	1.23	1.25	1.25	1.20	1.14	1.09	1.04	0.98	0.94	0.93	0.94	0.94	0.86
0.85	0.85	0.88	0.86	0.85	0.79	0.66	0.56	0.56	0.46	0.43	0.39	0.32	0.33	0.33	0.22	0.20

.....

V. Software Packages to Access DAMEE Data Sets

All DAMEE data files are written in ASCII code. Since OTIS is an operational package, there are certain Navy standards to follow. We did not modify OTIS input and output formats because we believe some users may want to use both our "research-quality" data sets and "operational-quality" data sets for comparison study.

DAMEE participants have developed many programs to process DAMEE data for interpolation into their model grids and displaying the fields. Here, we provide a few FORTRAN programs to help new users understand the internal structure of OTIS input and output data files. However, this does not suggest that the programs listed below are the most efficient ones.

(1) Program to read OTIS analysis and write out in 3-D arrays:

```
c      Program to read in OTIS ASCII file and write out in formatted
c      file

c      Originator: C. Aaron Lai

      parameter (ii = 176, jj = 101, kk = 34)

      common / otisf / otish(ii,jj), otist(ii,jj,kk), otiss(ii,jj,kk)
      common / filenm / otisfl

      real      otisz(kk)
      character*80 otisfl, fname(3)

c      print "(' Enter OTIS filename   => ', $)"
      read (*,'(a80)') otisfl
c      print "(' Enter output filename for d. h. => ', $)"
      read (*,'(a80)') fname(1)
c      print "(' Enter output filename for temperature => ', $)"
      read (*,'(a80)') fname(2)
c      print "(' Enter output filename for salinity => ', $)"
      read (*,'(a80)') fname(3)

      call readotis( otisz )

      open (unit=1, file=fname(1), form='formatted', status='new')
      open (unit=2, file=fname(2), form='formatted', status='new')
      open (unit=3, file=fname(3), form='formatted', status='new')

      write (1,4) otish
      do k = 1, kk
```

```

        write (2,4) ((otist(i,j,k),i=1,ii),j=1,jj)
        write (3,4) ((otiss(i,j,k),i=1,ii),j=1,jj)
    end do
4 format(10f8.3)

    close (1)
    close (2)
    close (3)

    stop
    end

    subroutine ldotis(z)

c      This subroutine reads file containing output from otis analysis.

    parameter (ii = 176, jj = 101, kk = 34)
    parameter (specval = 1.e10)

    character*80 otisfl

    common / otisf / otish(ii,jj), otist(ii,jj,kk), otiss(ii,jj,kk)
    common / filenm / otisfl

    real    t(kk), s(kk), z(kk)
c    real    zstd(kk)

c    data zstd /      0.0,      2.5,      7.5,      12.5,      17.5,25.0,
c    1      32.5,      40.0,      50.0,      62.5,      75.0,      100.0,
c    2      125.0,      150.0,      200.0,      300.0,      400.0,      500.0,
c    3      600.0,      700.0,      800.0,      900.0,      1000.0,      1100.0,
c    4      1200.0,      1300.0,      1400.0,      1500.0,      1750.0,      2000.0,
c    5      2500.0,      3000.0,      4000.0,      5000.0 /

    print *, ' loading otis data'

c    do k = 1, kk
c        z(k)=zstd(k)
c    enddo

c    Define data file name and open file.

    open(9,file=otisfl,form='formatted',status='old')

c    Read fields from input file.

    mrec = ii * jj * 2

    do 10 irec = 1, mrec
c    read(9,5,end=12) i, j, rlon, rlat, dh, rmxdp
c    5 format(2(i5,1x),2(f7.2,1x),2(f7.3,1x))
    read(9,5,end=12) i, j, rlon, rlat, dh
c    5 format(2(i5,1x),2(f7.2,1x),f7.3,1x)

```

```

      read(9,6,end=12) (t(k), k=1, kk)
6 format(17f7.3/17f7.3)
      read(9,7,end=12) (s(k), k=1, kk)
7 format(17f7.3/17f7.3////)

      otish(i,j) = dh
      do 8 k = 1, kk
        if(t(k) .gt. -990.) then
          otist(i,j,k) = t(k)
        else
          otist(i,j,k) = specval
        endif

        if(s(k) .gt. -990.) then
          otiss(i,j,k) = s(k)
        else
          otiss(i,j,k) = specval
        endif
      8 continue
10 continue

12 print *, ' last i = ', i, ' j = ', j

      close(9)
      print *, ' finished loading otis data'

      return
      end

```

.....

(2) Program to perform 4-point bilinear and 16-point Bessel interpolation:

```

C      SUBROUTINE = LAOINP

C      ORIGINATOR : CHUNG-CHIENG LAI

C      THIS PROGRAM IS USED TO INTERPOLATE FROM THE LAT-LON OR LFM GRID TO
C      POINTS DEFINED IN THE ORIGINAL GRID FORMAT.  THE SUBROUTINE
C      USES EITHER A 16-POINTS BESSEL INTERPOLATION SCHEME OR A 4-POINTS
C      BI-LINEAR SCHEME.  THE INTERPOLATION CAN BE DONE FOR EITHER A
C      ARRAY OR A LINE DATA.

```

```

      SUBROUTINE LACINP(E, IM, JM, GLON, GLAT, A, ILON, ILAT, ID, FLON, FLAT,
+ , GRID1, GRID2)

```

```

C      E      = OUTPUT ARRAY INTERPOLATED TO HARVARD OR X-Y GRID VALUES
C      LOND    = THE LONGITUDE (OR X) DIMENSION OF E
C      LATD    = THE LATITUDE (OR Y) DIMENSION OF E
C      GLON    = A 2-D ARRAY OF LONGITUDE OF HARVARD GRID OR X-Y GRID
C      GLAT    = A 2-D ARRAY OF LATITUDE OF HARVARD GRID OR X-Y GRID
C      A      = INPUT ARRAY OF LAT-LON GRID VALUES

```

```

C      ILON   = LONGITUDE DIMENSION OF INPUT ARRAY
C      ILAT   = LATITUDE DIMENSION OF INPUT ARRAY
C      ID     = INDEX FOR 16-POINT (0) OR 4-POINT (1) INTERPOLATION
C      FLAT   = LATITUDE OF POINT (1,1) OF INPUT ARRAY
C      FLON   = LONGITUDE OF POINT (1,1) OF INPUT ARRAY
C      GRID   = GRID INTERVAL IN DEGREES (OR 1 FOR X-Y GRID)

      DIMENSION E(IM,JM), GLON(IM,JM), GLAT(IM,JM), A(ILON,ILAT)
      ASSIGN 2 TO K
      IF(ID .EQ. 1) ASSIGN 3 TO K
      DO 5 J = 1, JM
      DO 5 I = 1, IM
      RLON = GLON(I,J)
      RLAT = GLAT(I,J)
      X = (RLON - FLON) / GRID1 + 1.
      Y = (RLAT - FLAT) / GRID2 + 1.
      M = INT(X)
      N = INT(Y)
      DX = X - M
      DY = Y - N
      GO TO K, (2,3)

C      16-POINT BESSEL INTERPOLATION

2     DXX = 0.25 * (DX - 1.)
      DYY = 0.25 * (DY - 1.)

C      CONSIDER BOUNDARY POINTS

      M = MIN1 (ILON-2, MAX1 (2,M))
      N = MIN1 (ILAT-2, MAX1 (2,N))

      AA = A(M,N-1) + DX * (A(M+1,N-1) - A(M,N-1) + DXX * (A(M+2,N-1) -
      A(M+1,N-1) + A(M-1,N-1) - A(M,N-1)))
      AB = A(M,N) + DX * (A(M+1,N) - A(M,N) + DXX * (A(M+2,N) - A(M+1,N)
      + A(M-1,N) - A(M,N)))
      AC = A(M,N+1) + DX * (A(M+1,N+1) - A(M,N+1) + DXX * (A(M+2,N+1) -
      A(M+1,N+1) + A(M-1,N+1) - A(M,N+1)))
      AD = A(M,N+2) + DX * (A(M+1,N+2) - A(M,N+2) + DXX * (A(M+2,N+2) -
      A(M+1,N+2) + A(M-1,N+2) - A(M,N+2)))
      E(I,J) = AB + DY * (AC - AB + DYY * (AD - AC + AA - AB))
      GO TO 5

C      4-POINT BI-LINEAR INTERPOLATION

C      CONSIDER BOUNDARY POINTS

3     M = MIN1 (ILON-1, MAX1 (1,M))
      N = MIN1 (ILAT-1, MAX1 (1,N))

      E(I,J) = (1. - DY) * ((1. - DX) * A(M,N) + DX * A(M+1,N))
      + DY * ((1. - DX) * A(M,N+1) + DX * A(M+1,N+1))

```

```

5  CONTINUE
   RETURN
   END

```

.....

(3) Programs to plot OTIS3 input data and output file using NCAR GKS package.

a) Program to plot OTIS3 input data.

```

program plot_data.f

C   Author: WEN QIAN

C   This program uses NCAR's GKS to plot OTIS output.
C   It is presented by color solid fill.

parameter (nclvl = 30, dg = 0.1, cmax = 32., cmin = 2.)

common /colors/ nclr,nic,rgb(3,405)
common /yrmdy/ iyr, imn, idy

integer      iclr(nclvl)
real         xc(5), yc(5)
character    lbs*2

data iclr /223,205,187,169, 88,  7, 18, 36, 45, 54,
+         63, 72, 81, 79, 77,154,235,379,361,343,
+         334,325,244,163, 82,100,181,199,280,298/

C
C
C   Get job control parameters and read plot data

call get_parm
cint = (cmax - cmin) / float(nclvl)

C   Initialize NCAR's GKS plotting package

call ginit
call gopwk(9,1,3)
call setcol(rgb,iclr,nclvl)

call otisplot(1)
call mcsstplot(2)
call bogusplot(3)
call xbtplot(4)

C   Put label

call label

```


C Plot Lab Bar

```

call set ( 0.1, 0.9, 0.05, 0.1, 0.0, 1.0 ,0.0, 1.0, 1)
yc(1) = .0
yc(2) = 1.
yc(3) = 1.
yc(4) = .0
yc(5) = .0
dyc = yc(2) - yc(1)
ych = yc(1) - dyc / 2.
cs = dyc * .012
dyp = 1. / nclvl
xc(1) = 0.
xc(2) = xc(1)
xc(3) = dyp
xc(4) = xc(3)
xc(5) = xc(1)
call gslwsc (2.)
do ic = 1, nclvl
  call clrbox(xc,yc,5,ic+1)
  if (ic .eq. 1) then
    write (lbs,'(i2)') nint(cmin)
    call plchq (xc(1),ych,lbs,cs,0.,0.)
  elseif (ic .eq. nclvl) then
    write (lbs,'(i2)') nint(cmax)
    call plchq (xc(3),ych,lbs,cs,0.,0.)
  endif
  xc(1) = xc(3)
  xc(2) = xc(1)
  xc(3) = xc(3) + dyp
  xc(4) = xc(3)
  xc(5) = xc(1)
enddo
call box(1)
call gslwsc (1.)

call frame

```

C Close GKS plot

```

call gclwk(9)
call clsgks

stop
end

```

.....

```

subroutine otisplot(np)

```

```

parameter (im =176, jm=101)
parameter (nplot = 1, azstd = 0.0)
parameter (nclvl = 30, dg = 0.1, cmax = 32., cmin = 2.)

```

```

common /corner/ latmn, latmx, lngmn, lngmx

DIMENSION temp(34),salt(34),anom(34),err(34)
DIMENSION salt_lev(im, jm)
DIMENSION iz1(504),iz2(504)
real xc(5), yc(5), x(5), y(5)
do j = 1, jm
do i = 1, im
    salt_lev(i, j) = -99.99
enddo
enddo

call background( np )

tmin = 100.
tmax = 0.

smin = 100.
smax = 0.

read (10, '(a80)' )

1 read(10, '(2(i5,1x),2(f7.2,1x))',end=5)
1 i,j,aalon,aalat
read(10, '(17(f7.3),/,17(f7.3))') temp
read(10, '(17(f7.3),/,17(f7.3))') salt
read(10, '(17(f7.3),/,17(f7.3))') anom
read(10, '(17(f7.3),/,17(f7.3))') err

airec=(50.0-aalat)*12.0
irec=int(airec)
wlat=airec-float(irec)
if (wlat.le..0) wlat=1.0
    iirec=irec+1
    read(50,rec=iirec)iz1
    read(50,rec=iirec+1)iz2
    ailon=(82.0+aalon)*12.0
    ilon=int(ailon)
    iilon=ilon+1
    wlon=ailon-float(ilon)
    if(wlon.le.0.0) wlon=1.0
        zz=float(iz1(iilon))*wlon*wlat+float(iz1(iilon+1))
        *wlat*(1.0-wlon)
1      +float(iz2(iilon))*wlon*(1.0-wlat)+float(iz2(iilon+1))
1      *(1.0-wlon)*(1.0-wlat)
    if(zz.ge.azstd) then
        salt_lev(i,j)=-99.99
        go to 1
    endif

    tmin = amin1(tmin, temp(nplot))
    tmax = amax1(tmax, temp(nplot))
    smin = amin1(smin, salt(nplot))
    smax = amax1(smax, salt(nplot))

```

```

salt_lev(i,j) = salt(nplot)
if(temp(nplot).le.-10.) go to 1
  X(1) = aalon-dg
  X(2) = aalon+dg
  X(3) = X(2)
  X(4) = X(1)
  X(5) = X(1)
  Y(1) = aalat+dg
  Y(2) = Y(1)
  Y(3) = aalat-dg
  Y(4) = Y(3)
  Y(5) = Y(1)

```

C Draw the bar by filling all of the individual boxes.

```

do ii = 1, 5
  call maptrn (y(ii),x(ii),xc(ii),yc(ii))
end do

```

C Draw the bar by filling all of the individual boxes.

```

cint = (cmax - cmin) / float(nc1v1)
ic = int((temp(nplot) - cmin) / cint) + 1
ic = max0(min0(ic,nc1v1),1)
call clrbox (xc,yc,5,ic+1)

```

```

go to 1

```

```

5 call background( np )
  print *, ' tmin =', tmin, '      tmax =', tmax
  print *, ' smin =', smin, '      smax =', smax

```

```

return
end

```

.....

```

subroutine mcsstplot(np)

```

```

parameter (nc1v1 = 30, dg = 0.1, cmax = 32., cmin = 2.)

```

```

common /corner/ latmn, latmx, lngmn, lngmx

```

```

real      alat(5), alon(5), sst(5)
real      xc(5), yc(5), x(5), y(5)

```

```

call background(np)

```

```

sstmin = 100.
sstmax = 0.

```

```

alatmn = float(latmn)
alatmx = float(latmx)
alngmn = float(lngmn)

```

```

    alngmx = float(lngmx)

1 read (20,2,end=5) (alat(i),alon(i),sst(i),i=1,5)
2 format (5(9x,f4.2,1x,f5.2,f4.1,1x))
do 200 i = 1, 5
    if(alat(i).lt.alatmn.or.alat(i).gt.alatmx) goto 200
    if(alon(i).lt.alngmn.or.alon(i).gt.alngmx) goto 200
    if(alat(i) .ne. 0.) then
        sstmin = amin1(sstmin, sst(i))
        sstmax = amax1(sstmax, sst(i))

        x(1) = alon(i) - dg
        x(2) = x(1)
        x(3) = alon(i) + dg
        x(4) = x(3)
        x(5) = x(1)
        y(1) = alat(i) - dg
        y(2) = alat(i) + dg
        y(3) = y(2)
        y(4) = y(1)
        y(5) = y(1)

C    Draw the bar by filling all of the individual boxes.

        do ii = 1, 5
            call maptrn (y(ii),x(ii),xc(ii),yc(ii))
        end do

C    Draw the bar by filling all of the individual boxes.

        cint = (cmax - cmin) / float(nclvl)
        ic = int((sst(i) - cmin) / cint) + 1
        ic = max0(min0(ic,nclvl),1)
        call clrbox (xc,yc,5,ic+1)
    end if
200 continue
go to 1

5 call background(np)
    print *, ' sstmin =', sstmin, '      sstmax =', sstmax

return
end

. . . . .

subroutine xbtplot(np)

parameter (nclvl = 30, dg = 0.1, cmax = 32., cmin = 2.)

common /yrmdy/ iyr, imn, idy

real x(5),y(5), xc(5), yc(5), zs(200), ts(200)

```

```

call jyrday (iyr, imn, idy, jyd, 1)
jyd1 = jyd + 30
jyd2 = jyd - 30

cint = (cmax - cmin) / float(nclvl)

call background(np)

212  continue
      read(40,5000,end=444)iv,imon,iday,alat,alon,npt
5000  format(2x,3i2,4x,2f8.2,10x,i2)

      npts=npt/2
      read(40,6000)(zs(i),ts(i),i=1,npts)
6000  format(8(2x,f6.1,2x,f5.2))
      call jyrday (iy,imon,iday,jydat,1)

      if(jydat.gt.jyd1) go to 212
      if(jydat.lt.jyd2) go to 212
      XC(1) = alon-dg
      XC(2) = alon+dg
      XC(3) = xc(2)
      XC(4) = xc(1)
      XC(5) = xc(1)
      YC(1) = alat+dg
      YC(2) = yc(1)
      YC(3) = alat-dg
      YC(4) = yc(3)
      YC(5) = yc(1)

C
      do 2222 ii=1,5
2222  CALL MAPTRN (yc(ii),xc(ii),X(ii),Y(ii))
C      Draw the bar by filling all of the individual boxes.
C
      IC = INT((ts(1) - CMIN) / CINT) + 1
      IC = MAX0(MIN0(IC,NCLVL),1)
      CALL CLRBOX (X,Y,5,IC+1)
      go to 212

444  return
      end

. . . . .

subroutine bogusplot(np)

parameter (nclvl = 30, dg = 0.1, cmax = 32., cmin = 2.)
DIMENSION YED(500),XED(500), x(5), y(5), xc(5), yc(5),z(500)

call background(np)

CALL GSCR(1,50,1.,1.,0.)
CALL GSPLCI (50)
CALL GSLWSC (5.)

```

```

      READ (30, *)
      READ (30, '(26X,A8,29X,I3)',ERR=101) DTG, NF
C     COMPUTE THE NUMBER OF BOGUS INPUT CARDS TO READ
C
      IF (MOD(NF,3) .EQ. 0) THEN
          NLINE = NF / 3
      ELSE
          NLINE = NF / 3 + 1
      END IF
C
C     READ IN FRONT PATH CARDS - LAT, LON AND CERTAINTY
C
      N = 0
      DO 20 L = 1, NLINE
          M = N + 1
          N = M + 2
          IF (N .GT. NF) N = NF
          READ (30, '(16X,3(F6.2,1X,F7.2,I3,4X))',ERR=102)
          *      (YED(J), XED(J), Z(J), J = M, N)
      20  CONTINUE
C
      go to 202
101  write(6,*) 'read bogus ERROR !'
      stop(9999)
102  write(6,*) 'read bogus ERROR !'
      stop(999)
103  write(6,*) 'read bogus ERROR !'
      stop(99)
104  write(6,*) 'read bogus ERROR !'
      stop(9)

202  CALL MAPIT (YED(1),XED(1),0)
      DO 120 J = 2, NF
          CALL MAPIT (YED(J),XED(J),1)
120  CONTINUE
      CALL MAPIQ

      CALL GSLWSC (2.)

10  continue
      READ (30, *, end = 99)
      READ (30, '(1X,I2,1X,I1,21X,A8,8X,F4.1,1X,I3)',end=99,ERR=103)
      *      IDNO, RTYPE, RDTG, RSST, ISWRL
      READ (30, '(16X,F6.2,1X,F7.2,I3,3X,I3,2(6X,I3))',end=99,ERR=104)
      *      RLAT, RLON, ICONF, IDIREC, MAJOR, MINOR

      X(1) = rlon - float(major)/100.
      X(2) = rlon + float(major)/100.
      X(3) = X(2)
      X(4) = X(1)
      X(5) = X(1)
      Y(1) = rlat + float(major)/100.
      Y(2) = Y(1)
      Y(3) = rlat - float(major)/100.

```

```

        Y(4) = Y(3)
        Y(5) = Y(1)
C      Dr the bar by filling all of the individual boxes.

cint = (cmax - cmin) / float(nclvl)
ic = int((rsst - cmin) / cint) + 1
ic = max0(min0(ic,nclvl),1)
call clrbox (xc,yc,5,ic+1)

C      Draw a cross for ring

        CALL GSPLCI (ic + 1)
        CALL MAPIT (RLAT, X(1),0)
        CALL MAPIT (RLAT, X(2),1)
        CALL MAPIQ
        CALL MAPIT (Y(1), RLON,0)
        CALL MAPIT (Y(3), RLON,1)
        CALL MAPIQ

        go to 10

99      CALL GSLWSC (1.)
        CALL GSPLCI (1)

        return
        end

. . . . .

subroutine background( np )

common /pframe/ tlon, tlat, blon, blat, width
common /corner/ latmn, latmx, lngmn, lngmx

c      Draw EZMAP background

jprj = 9
rota = 0.
plon = float(lngmn + lngmx) / 2.
plat = 0.
p1 = float(latmn)
p2 = float(lngmn)
p3 = float(latmx)
p4 = float(lngmx)
jlts = 2
jgrd = 5
iout = 4
idot = 0

C      call supmap(jprj,plat,plon,rota,p1,p2,p3,p4,jlts,jgrd,iout,
1      idot,ierr,np)
        return
        end

. . . . .

```

```

subroutine get_parm

originator:  Hernan Arango

common /corner/ latmn, latmx, lngmn, lngmx
common /yrindy/  iyr, imn, idy
integer          unit
character*60      fname

C   Get min, max of lat and long.

      read (5,*) latmn, latmx
      read (5,*) lngmn, lngmx

      read (5,*) iyr, imn, idy

C   Set input files units

      do k = 1, 4
        unit = k * 10

C   Get input filenames for PLOT

          read (5,'(a)') fname
          open ( unit, file=fname, form='formatted',
&              status='old' )

      enddo

      open(50,file='/epoch/data1/qian/data4/etopo5.gs',
1        form='unformatted',access='direct',recl=2016)

      return
      end

. . . . .

C
C   SUBROUTINE GINIT
C
C   COMMON /COLORS/ NCLR,NIC,RGB(3,405)
C
C   Declare an array to hold the GKS "aspect source flags"
C   and initialize the values in the aspect-source-flag array
C
      DIMENSION IASF(13)
      DATA IASF/13*1/

C
C   Open GKS
C
      CALL OPNGKS

C
C   Turn off the clipping indicator
C
      CALL GSCLIP(0)

```



```

C      Force solid fill
C
C      CALL GSFAIS(1)
C
C      Set all the GKS aspect source flags to 'individual'
C
C      CALL GSASF(IASF)
C
C      Call a routine to define RGB triplets
C
C      CALL COLSET(RGB)
C
C      RETURN
C      END
C
C      . . . . .
C
C      SUBROUTINE COLSET (RGB)
C
C      Define the RGB color triples needed. This is done by filling the
C      RGB array with all 405 permutations for a 9 x 9 color cube in 5
C      plots. All values are normalized to fall in the range 0 to 1.
C
C      DIMENSION RGB(3,405)
C      DIMENSION CLRS(9)
C
C      DATA CLRS / 0., 32., 64., 96., 128., 160., 192., 224., 255. /
C
C      INDEX = 1
C      DO I=1,5
C        DO J=1,9
C          DO K=1,9
C            RGB (1,INDEX) = CLRS(2*I-1)/255.0
C            RGB (2,INDEX) = CLRS(J)/255.0
C            RGB (3,INDEX) = CLRS(K)/255.0
C            INDEX = INDEX + 1
C          ENDDO
C        ENDDO
C      ENDDO
C
C      RETURN
C      END
C
C      . . . . .
C
C      SUBROUTINE BOX (ICS)
C
C      Draw white box around current window
C      ICS = 0/1 -> draw in viewport/world coordinate system
C
C      DIMENSION X(5),Y(5)
C
C      CALL GETSET(VL,VR,VB,VT,UL,UR,UB,UT,LL)
C      X(1) = UL

```

```

X(2) = UL
X(3) = UR
X(4) = UR
X(5) = UL
Y(1) = UB
Y(2) = UT
Y(3) = UT
Y(4) = UB
Y(5) = UB
IF (ICS.EQ.0) THEN
X(1) = VL
    X(2) = VL
    X(3) = VR
    X(4) = VR
    X(5) = VL
    Y(1) = VB
    Y(2) = VT
    Y(3) = VT
    Y(4) = VB
    Y(5) = VB
ENDIF
CALL GSFAIS(1)
CALL GSPLCI(1)
CALL GPL(5,X,Y)
C
RETURN
END
C
. . . . .
C
SUBROUTINE CLRBOX (XCS,YCS,NCS,INDX)
C
DIMENSION XCS(*),YCS(*)
C
Color the box.
C
CALL GSFACI (INDX)
CALL GFA      (NCS-1,XCS,YCS)
C
RETURN
END
C
. . . . .
C
SUBROUTINE LABEL
common /yrandy/ iyr, imn, idy
C
character ts*35, title*60
C
Put a label just above the top of the plot. The SET call is
used here for label at right place.
C
CALL      SET ( 0.0, 1.0, 0.0, 1.0, 0.0, 1.0, 0.0, 1.0, 1 )

```

```

        cs1 = 0.014
        cs2 = 0.01

        write(title,3) iyr, imn, idy
3       format(17x,'OTIS3 SST and Input Data',10x,i2,2('/',i2.2))
        call plchhq(0.5, 0.975, title, cs1, 0., 0.)

        write(ts,4)
4       format('OTIS SST' )
        call plchhq (0.262, 0.94, ts, cs2, 0., 0.)

        write(ts,5)
5       format(30x,'MCSST')
        call plchhq (0.738, 0.94, ts, cs2, 0., 0.)

        write(ts,6)
6       format('BOGUS')
        call plchhq (0.262, 0.52, ts, cs2, 0., 0.)

        write(ts,7)
7       format(32x,'XBT')
        call plchhq (0.738, 0.52, ts, cs2, 0., 0.)
C
        RETURN
        END
C
* . . . . .
C
        SUBROUTINE SETCOL (RGB,INDEX,NUM)
C
C       Define color indices to contain the desired colors.
C
        DIMENSION RGB(3,405),INDEX(1)
C
        CALL GSCR(1,0,0.,0.,0.)
        CALL GSCR(1,1,1.,1.,1.)
C
        DO N=1,NUM
            NDX = INDEX(N)
            CALL GSCR(1,N+1,RGB(1,NDX),RGB(2,NDX),RGB(3,NDX))
        ENDDO
C
        RETURN
        END
C
* . . . . .
C
        SUBROUTINE SUPMAP (JPRJ,PLAT,PLON,ROTA,PLM1,PLM2,PLM3,PLM4,JLTS,
+ JGRD,IOUT,IDOT,IERR,np)
C
        DIMENSION PLM1(2),PLM2(2),PLM3(2),PLM4(2)
C
C       Declare required common blocks.  See MAPBD for descriptions of these
C       common blocks and the variables in them.

```

```

COMMON /MAPCMS/ DDCT(5),LDCT(5),PDCT(10)
CHARACTER*2      DDCT,LDCT,PDCT
SAVE /MAPCMS/
COMMON /MAPCMB/ IIER
SAVE /MAPCMB/

C
  DIMENSION LPRJ(10),LLTS(5)

C
  DATA LPRJ / 2,3,1,4,5,6,10,7,8,9 /
  DATA LLTS / 1,2,5,4,3 /

C
  Set EZMAP's grid-spacing parameter.
C
  CALL MAPSTI ('GR',MOD(IABS(JGRD),1000))

C
  Set EZMAP's outline-selection parameter.
C
  IF (IABS(IOUT).EQ.0.OR.IABS(IOUT).EQ.1) THEN
    I=1+2*IABS(IOUT)+(1+ISIGN(1,JPRJ))/2
  ELSE
    I=MAX(1,MIN(5,IOUT))
  END IF

C
  CALL MAPSTC ('OU',DDCT(I))

C
  Set EZMAP's perimeter-drawing flag.
C
  CALL MAPSTL ('PE',JGRD.GE.0)

C
  Set EZMAP's grid-line-labelling flag.
C
  CALL MAPSTL ('LA',MOD(IABS(JGRD),1000).NE.0)

C
  Set EZMAP's dotted-outline flag.
C
  CALL MAPSTI ('DO',MAX(0,MIN(1,IDOT)))

C
  if (np.eq.1) then
    call mappos (0.05, 0.475, 0.54, 0.94)
  elseif (np.eq.2) then
    call mappos (0.525, 0.95, 0.54, 0.94)
  elseif (np.eq.3) then
    call mappos (0.05, 0.475, 0.12, 0.52)
  elseif (np.eq.4) then
    call mappos (0.525, 0.95, 0.12, 0.52)
  else
    call mappos (0.05, 0.95, 0.05, 0.95)
  endif

C
  Set EZMAP's projection-selection parameters.
C
  I=MAX(1,MIN(10,IABS(JPRJ)))
  CALL MAPROJ (PDCT(LPRJ(I)),PLAT,PLON,ROTA)
C

```

```

C      Set EZMAP's rectangular-limits-selection parameters.
C
C      I=LLTS(MAX(1,MIN(5,IABS(JLTS))))
C      CALL MAPSET (LDCT(I),PLM1,PLM2,PLM3,PLM4)
C
C      Draw the map.
C
C      if (np.le.4) CALL MAPDRW
C
C      Return the error flag to the user.
C
C      IERR=IIER
C
C      Done.
C
C      RETURN
C
C      END
C
C      .....
C
C      SUBROUTINE JYRDAY (IY,IM,ID,JYD,ICV)
C      originator: D.-S. Ko
C      Convert Y/M/D to JYD (ICV=1)
C      Y/JYD to M/D (ICV=-1)
C
C      DIMENSION JM0(13,2)
C      DATA JM0/0,31,59,90,120,151,181,212,243,273,304,334,365,
&          0,31,60,91,121,152,182,213,244,274,305,335,366/
C
C      IF (MOD(IY,4).EQ.0) THEN
C          IE = 2
C      ELSE
C          IE = 1
C      END IF
C
C      IF (ICV.GT.0) THEN
C          JYD = JM0(IM,IE) + ID
C      ELSE IF (ICV.LT.0) THEN
C          IM = 1
C          DO WHILE (JYD.GT.JM0(IM+1,IE))
C              IM = IM + 1
C          END DO
C          ID = JYD - JM0(IM,IE)
C      END IF
C      RETURN
C      END
C
C      .....
C
C      SUBROUTINE CPMPXY (IMAP,XX,YY,FX,FY)
C
C      PARAMETER (NX=239,NY=171)
C      PARAMETER (IMM=NX+1,JMM=NY+1)

```

```
COMMON/TRANS/ GY(IMM,JMM),GX(IMM,JMM)
```

```
IF ( IMAP .EQ. 3) THEN
```

C

```
    II=IFIX(XX)
    PRX=XX-FLOAT(II)
    IM=MAX0(II,1)
    IP=MIN0(IM+1,IMM)
    JJ=IFIX(YY)
    PRY=YY-FLOAT(JJ)
    JM=MAX0(JJ,1)
    JP=MIN0(JM+1,JMM)
    FFX=PRX*(PRY*GX(IP,JP)+(1.-PRY)*GX(IP,JM))
1      +(1.-PRX)*(PRY*GX(IM,JP)+(1.-PRY)*GX(IM,JM))
    FFY=PRX*(PRY*GY(IP,JP)+(1.-PRY)*GY(IP,JM))
1      +(1.-PRX)*(PRY*GY(IM,JP)+(1.-PRY)*GY(IM,JM))
    CALL MAPTRN(FFY,FFX,FX,FY)
ENDIF
RETURN
END
```

.....

b) Program to plot OTIS3 temperature and salinity.

```
program plot_otis.f
```

C

```
author: Wen Qian
```

C

```
This program uses NCAR's GKS to plot OTIS output.
```

C

```
It is presented by color solid fill.
```

```
parameter (nclvl = 30, im =176, jm=101)
```

```
common /pltdat/ plttitle(4), fname(2), unt(2)
```

```
common /colors/ nclr,nic,rgb(3,405)
```

```
common /yrandy/ iyr, imn, idy
```

```
common /tminmax/ idepth(4), tmin(4), tmax(4)
```

```
common /corner/ latmn, latmx, lngmn, lngmx
```

```
integer iclr(nclvl), unt(2), level(4)
```

```
DIMENSION temp(34),salt(34),anom(34),err(34),zstd(34)
```

```
DIMENSION salt_lev(im, jm)
```

```
DIMENSION iz1(504),iz2(504)
```

```
real xc(5), yc(5), x(5), y(5)
```

```
character fname(2)*60, plttitle(4)*60, lbs*2
```

```
data iclr /223,205,187,169, 88, 7, 18, 36, 45, 54,
```

```
+ 63, 72, 81, 79, 77,154,235,379,361,343,
```

```
+ 334,325,244,163, 82,100,181,199,280,298/
```

```
data level /9, 15, 18, 30/
```

```
data dg / 0.1 /
```

C

```
INITIALIZE OTIS STANDARD DEPTH ARRAY
```

```

C      DATA ZSTD /0., 2.5, 7.5, 12.5, 17.5, 25., 32.5, 40., 50., 62.5,
*          75., 100., 125., 150., 200., 300., 400., 500., 600.,
*          700., 800., 900., 1000., 1100., 1200., 1300., 1400.,
*          1500., 1750., 2000., 2500., 3000., 4000., 5000./

C
C      Get job control parameters and read plot data

      call get_parm
      cmax = 32.
      cmin = 2.
      cint = (cmax - cmin) / float(nc1vl)

C      Initialize NCAR's GKS plotting package

      call ginit
      call gopwk(9,1,3)
      call setcol(rgb,iclr,nc1vl)

      do j = 1, jm
        do i = 1, im
          salt_lev(i, j) = -99.99
        enddo
      enddo

      DO 1000 np = 1, 4
        nplot = level( np )

        call background( np )

        tmin(np) = 100.
        tmax(np) = 0.

        smin = 100.
        smax = 0.

        read (unt(1),'(a80)' )

1      read(unt(1),'(2(i5,1x),2(f7.2,1x))',end=5)
1      i,j,aalon,aalat
      read(unt(1),'(17(f7.3),/,17(f7.3))') temp
      read(unt(1),'(17(f7.3),/,17(f7.3))') salt
      read(unt(1),'(17(f7.3),/,17(f7.3))') anom
      read(unt(1),'(17(f7.3),/,17(f7.3))') err

      airec=(50.0-aalat)*12.0
      irec=int(airec)
      wlat=airec-float(irec)
      if (wlat.le.0.0) wlat=1.0
      iirec=irec+1
      read(40,rec=iirec)iz1
      read(40,rec=iirec+1)iz2
      ailon=(82.0+aalon)*12.0
      ilon=int(ailon)

```

```

iilon=iilon+1
wlon=ailon-float(iilon)
if(wlon.le.0.0) wlon=1.0
zz=float(iz1(iilon))*wlon*wlat+float(iz1(iilon+1))
1  *wlat*(1.0-wlon)
1  +float(iz2(iilon))*wlon*(1.0-wlat)+float(iz2(iilon+1))
1  *(1.0-wlon)*(1.0-wlat)

```

```

      azstd = -zstd(nplot)
if(zz.ge.azstd) then
      salt_lev(i,j)=-99.99
      go to 1
endif

```

```

tmin(np) = amin1(tmin(np), temp(nplot))
tmax(np) = amax1(tmax(np), temp(nplot))
smin = amin1(smin, salt(nplot))
smax = amax1(smax, salt(nplot))

```

```

salt_lev(i,j) = salt(nplot)
if(temp(nplot).le.-10.) go to 1

```

```

      X(1) = aalon-dg
      X(2) = aalon+dg
      X(3) = X(2)
      X(4) = X(1)
      X(5) = X(1)
      Y(1) = aalat+dg
      Y(2) = Y(1)
      Y(3) = aalat-dg
      Y(4) = Y(3)
      Y(5) = Y(1)

```

C Draw the bar by filling all of the individual boxes.

```

do ii = 1, 5
      call maptrn (y(ii),x(ii),xc(ii),yc(ii))
end do

```

```

ic = int((temp(nplot) - cmin) / cint) + 1
ic = max0(min0(ic,nclvl),1)
call clrbox (xc,yc,5,ic+1)

```

```

go to 1

```

```

5  call background( np )
   print *, ' tmin =', tmin(np), '      tmax =', tmax(np)
   print *, ' smin =', smin, '      smax =', smax

```

C contour Salt

```

alatmn = float(latmn)
alatmx = float(latmx)
alngmn = float(lngmn)

```



```

alngmx = float(lngmx)

call cpseti('MAP - MAPPING FLAG', 1)
call cpsetr('XC1 - X COORDINATE AT INDEX1', alngmn)
call cpsetr('XCM - X COORDINATE AT INDEXM', alngmx)
call cpsetr('YC1 - Y COORDINATE AT INDEX1', alatmn)
call cpsetr('YCN - Y COORDINATE AT INDEXN', alatmx)
call cpsetr('SPV - SPECIAL VALUE', -99.99)

if(np.eq.1) then
  call cpcnrc(salt_lev, im, im, jm, 0., 0., 0.2, 1, -1, -680)
elseif(np.eq.2.or np.eq.3) then
  call cpcnrc(salt_lev, im, im, jm, 0., 0., 0.1, 1, -1, -680)
else
  call cpcnrc(salt_lev, im, im, jm, 0., 0., 0.05, 1, -1, -680)
endif

idepth(np) = int(zstd(nplot))

rewind(unt(1))

1000 continue

C   Put label

call label

C   Plot Lab Bar

call set ( 0.1, 0.9, 0.05, 0.1, 0.0, 1.0 ,0.0, 1.0, 1)
yc(1) = .0
yc(2) = 1.
yc(3) = 1.
yc(4) = .0
yc(5) = .0
dyc = yc(2) - yc(1)
ych = yc(1) - dyc / 2.
cs = dyc * .012
dyp = 1. / nclvl
xc(1) = 0.
xc(2) = xc(1)
xc(3) = dyp
xc(4) = xc(3)
xc(5) = xc(1)
call gslwsc (2.)
do ic = 1, nclvl
  call clrbox(xc,yc,5,ic+1)
  if (ic .eq. 1) then
    write (lbs,'(i2)') nint(cmin)
    call plchhq (xc(1),ych,lbs,cs,0.,0.)
  elseif (ic .eq. nclvl) then
    write (lbs,'(i2)') nint(cmax)
    call plchhq (xc(3),ych,lbs,cs,0.,0.)
  endif
endif

```

```

        xc(1) = xc(3)
        xc(2) = xc(1)
        xc(3) = xc(3) + dxp
        xc(4) = xc(3)
        xc(5) = xc(1)
    enddo
    call box(1)
    call gslwsc (1.)

    call frame

C    Close GKS plot

    call gclwk(9)
    call clsgks

    stop
    end

. . . . .

    subroutine Background( np )                [Same as in (3) a)]

. . . . .

    subroutine get_parm

    originator = Hernan Arango

    common /pltdat/ plttitle(4), fname(2), unt(2)
    common /corner/ latmn, latmx, lngmn, lngmx
    common /yrmdy/ iyr, imn, idy

    integer          unt(2)
    character*60      fname(2), plttitle(4)

C    Set input files units

    do k = 1, 2
        unt(k) = k + 10
    end do

C    Read job control file

C    Get min, max of lat and long.

    read (5,*) latmn, latmx
    read (5,*) lngmn, lngmx

    read (5,*) iyr, imn, idy

C    Get input filenames for PLOT

    read (5,'(a)') fname(1)

```

```

open ( unit=unt(1), file=fname(1), form='formatted',
&      status='old' )

read (5,*) isd

if (isd .gt. 0) then
  unt(2) = unt(1)
else
  read (5,'(a)') fname(2)
  open ( unit=unt(2), file=fname(2), form='formatted',
&      status='old' )
endif

C   open etop5 for mask

open(40,file='/epoch/data1/qian/data4/etopo5.gs',
1   form='unformatted',access='direct',recl=2016)
return
end

. . . . .
C
SUBROUTINE GINIT                                [Same as in (3) a)]
C
. . . . .
C
SUBROUTINE COLSET (RGB)                        [Same as in (3) a)]
C
. . . . .
C
SUBROUTINE BOX (ICS)                          [Same as in (3) a)]
C
. . . . .
C
SUBROUTINE CLRBOX (XCS,YCS,NCS,INDX)          [Same as in (3) a)]
C
. . . . .
C
SUBROUTINE LABEL
common /yrmdy/ iyr, imn, idy
common /tminmax/ idepth(4)
C
character ts*40, title*60

C   Put a label just above the top of the plot. The SET call is
C   used here for label at right place.
C
CALL SET ( 0.0, 1.0, 0.0, 1.0, 0.0, 1.0, 0.0, 1.0, 1 )

cs1 = 0.014
cs2 = 0.01

write(title,3) iyr, imn, idy
3 format(7x,'OTIS3 Temperature (C) and Salinity (ppt)',3x,

```

```

1          i2,2('/',i2.2))
  call plchhq(0.5, 0.975, title, cs1, 0., 0.)

  write(ts,4) idepth(1)
4 format(i4,' m')
  call plchhq (0.262, 0.94, ts, cs2, 0., 0.)

  write(ts,5) idepth(2)
5 format(31x,i4,' m')
  call plchhq (0.738, 0.94, ts, cs2, 0., 0.)

  write(ts,6) idepth(3)
6 format(i4,' m')
  call plchhq (0.262, 0.52, ts, cs2, 0., 0.)

  write(ts,7) idepth(4)
7 format(31x,i4,' m')
  call plchhq (0.738, 0.52, ts, cs2, 0., 0.)
C
  RETURN
  END
C
. . . . .
C
  SUBROUTINE SETCOL (RGB,INDEX,NUM)          [Same as in (3) a)]
C
. . . . .
C
  SUBROUTINE SUPMAP (JPRJ, PLAT, PLON, ROTA, PLM1, PLM2, PLM3, PLM4, JLTS,
+ JGRD, IOUT, IDOT, IERR, np)              [Same as in (3) a)]
C
. . . . .

```

c) Program to plot observed BT profiles or OTIS3 temperature profiles.

```

program temp_prof

c   originator: D.-S. Ko

c   This program plots ten BT profiles with a specified offset of X-values

parameter (nz = 34)
parameter (numprof = 110)
real temp(nz,numprof), atemp(nz,numprof)
real depth(nz,numprof), zstd(nz)
real deltemp, xlon(numprof), ylat(numprof)
character*80 dashp(numprof)
character*16 agdshn
character*80 filenm
character*20 title20

DATA ZSTD /0., 2.5, 7.5, 12.5, 17.5, 25., 32.5, 40., 50., 62.5,

```

```

*          75., 100., 125., 150., 200., 300., 400., 500., 600.,
*          700., 800., 900., 1000., 1100., 1200., 1300., 1400.,
*          1500., 1750., 2000., 2500., 3000., 4000., 5000./

call getenv('otis_out',filenm)
open(unit=11,file=filenm,form='formatted',status='old',err=999)
call getenv('ocnbog',filenm)
open(unit=22,file=filenm,form='formatted',status='old',err=999)
call getenv('title',title20)
C  write(6,*) 'input data file name ?'
C  read(5,*) filenm
C  open(11,file=filenm,status='old',err=999,form='formatted')

go to 10
999 write (6,*) 'open error for ',filenm
go to 500

10  print*, 'LONLAT = 1, input LON LAT from screen'
    print*, 'LONLAT = 2, input LON LAT from OCNBOG file'
    read*,lonlat

    print*, 'bottom depth of plot (meters), DEPTH = '
    read(5,*) dp
    dpm=9999.
    dpmin=9999.
    do 18 jj=1,nz
    dpmin=abs(zstd(jj)-dp)
    if(dpmin.lt.dpm) then
        nzz=jj
        dpm=dpmin
    endif
18  continue

    if (lonlat.eq.1) then
        print*, 'number of (LON LAT) pair'
        read(5,*)nu
        do 15 i=1,nu
            print*, 'LON = , LAT = '
            read(5,*)xlon(i),ylat(i)
            if(xlon(i).lt.-80..or.xlon(i).gt.-50.) then
                print*, 'LON is out range, LON = '
                read(5,*)xlon(i)
            elseif(ylat(i).lt.25..or.ylat(i).gt.45.) then
                print*, 'LAT is out range, LAT = '
                read(5,*)ylat(i)
            endif
15  continue

        elseif (lonlat.eq.2) then
            i=0
            C  write(6,*) 'input OCNBOG file name ?'
            C  read(5,*) filenm
            C  open(22,err=999,file=filenm,status='old')
            print*, 'every NPOINT from OCNBOG is plotted, NPOINT = '

```

```

        read(5,*)np
20      do 25 ii=1,np
          read(22,*,end=50)
25      continue
22      read(22,*,end=50) xl,y1
        if(xl.lt.-80..or.xl.gt.-50.) then
          go to 22
        elseif(y1.lt.25..or.y1.gt.45.) then
          go to 22
        endif
        write(6,*)
        write(6,*)'plotting point along the AXIS'
        write(6,*)'LON = ',xl,',', 'LAT = ',y1
        do 30 jj=1,11
          xlon(jj+i)=xl
          ylat(jj+i)=y1-1.2+0.2*float(jj)
30      continue
        i=i+jj
        go to 20
50      nu=i

    else
      go to 10
    endif

    print*, 'Enter delt_temp:'
    read*, dtemp

    do 80 jk=1,numprof
    do 80 ik=1,nz
      atemp(ik,jk)=0.0
      depth(ik,jk)=0.0
      temp(ik,jk)=0.0
80    continue

    call opngks

    do 200 j = 1,nu

      ix=int((xlon(j)+82.)*5.)+1
      jy=int((ylat(j)-27.)*5.)+1
      irec=161*(jy-1)+ix

      if(irec.gt.1) then
        do 300 ij=1,irec-1
          read(11,*)
          read(11,*)
          read(11,*)
          read(11,*)
          read(11,*)
          read(11,*)
          read(11,*)
          read(11,*)
          read(11,*)
          read(11,*)
        enddo
      endif
    enddo

```

300 continue

endif

```
read(11,*)
read(11,*)(atemp(i,j),i=1,17)
read(11,*)(atemp(i,j),i=18,34)
read(11,*)
read(11,*)
read(11,*)
read(11,*)
read(11,*)
read(11,*)
```

rewind(11)

```
j1=int(xlon(j))
j2=int(ylat(j))
write(dashp(j),1001)j1,j2
deltemp = dtemp * float(j-1)
do i = 1, nzz
  depth(i,j) = -zstd(i)
  temp(i,j) = atemp(i,j) + deltemp
enddo
```

```
do i=nzz,34
  depth(i,j) = -zstd(nzz)
  temp(i,j) = temp(nzz,j)
enddo
```

200 continue

```
close(11)
close(22)
```

c
c

```
call agseti ('DASH/SELECTOR.',nu)
call agseti ('DASH/LENGTH.',80)
do i = 1, nu
  call agsetc (agdshn(i), dashp(i))
enddo
```

```
call agsetc('LABEL/NAME.','L')
call agseti('LINE/NUMBER.',100)
call agsetc('LINE/TEXT.','DEPTH (METERS)$')
```

```
call agsetc('LABEL/NAME.','B')
call agseti('LINE/NUMBER.',-100)
call agsetc('LINE/TEXT.','TEMPERATURE (C)$')
```

```
call agseti ('ROW.',2)
```

nuu=nu

```

        if(lonlat.eq.2) then
            nuu=nu-1
        endif
        call ezmxy(temp,depth,nz,nuu,nz,title20)
        call clsgks
c
1001  format('$$$$$$$$$$$$$$$$$$$$$$$$$$$$$', 'LON = ', I3, ' ')
1      '$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$', 'LAT = ', I3, ' ')
500   stop
      end
. . . . .

```

(4) Format of XBT data in the DAMEE test cases.

The two digits in the filename are the year. The data set includes REX underflights, the Harvard flights AXBT transfered through NEOC, FNOC and NODC.

```

FORMAT:
      ihour='0000'
      write(10,5000) iy//im//iday//ihour,alat,alon,npts*2
5000  format(2x,a10,2f8.2,10x,i2)
      write(10,6000) (zs(i),ts(i),i=1,npts)
6000  format(8(2x,f6.1,2x,f5.2))
. . . . .

```

(5) Program to read ring data (rg_data.****) and process for OTIS input.

```

program ring_con

dimension iedtyp(100),clat(100),clon(100),iradkm(100)
character*1 i1
character*100 filenm

call getenv('ringin',filenm)
open(unit=9,file=filenm,form='formatted')
call getenv('ringout',filenm)
open(unit=10,file=filenm,form='formatted')

      i=0
1      i=i+1
      read(9,1000,end=2) i1,clat(i),clon(i),radkm
1000  format(a1,6x,f7.4,4x,f7.4,14x,f4.1)

      if(i1.eq.'w') iedtyp(i)=1
      if(i1.eq.'c') iedtyp(i)=-1
      iradkm(i)=int(radkm)
      write(10,2000) iedtyp(i),clat(i),clon(i),iradkm(i)

```



```
2000  format(8x,i3,f7.2,f7.2,8x,i4)
```

```
      go to 1
```

```
2      stop  
      end
```

.....

VI. Suggestions for DAMEE Data Usage

The DAMEE data set is a big collection of observed data (XBT, MCSST), subjective analysis (bogus), climatology (GDEM), and objective analysis (OTIS output) for several cases of different lengths. The main thrust in the preparation of DAMEE data was "iterative quality control." The subjective bogus information for Cases 1, 2, and 3 had a long history of analysis and verification from the CIMREP study to the DAMEE experiment. All cases had been tested by participating models to be dynamically-reasonable scenarios. On the other hand, extensive effort had been devoted to the quality control of in-situ data (XBT) and remote sensing data (MCSST). The precious one-month case (Case 4) was thoroughly checked from initial patching of AVHRR imagery, analysis of Surface North Wall and rings (bogusing) through dynamical testing by models. Case 5 provided a continual series of good analysis with superior consistency and continuity of the Gulf Stream system.

By combining the high-quality analysis of observation with the most technically-advanced ocean thermal structure analysis system (OTIS), we obtained an excellent 3-D data product for mesoscale ocean modeling which had not been obtained before. Therefore, we believe that this data set is worth making available to the oceanography community for modeling, observation, and theoretical researches.

In the Gulf Stream modeling aspect, this data set gives the modeler tremendous help in model initialization. The high-resolution 3-D temperature and salinity fields can be used in model spinup. Of course, a model should obtain dynamical balance before any forecast run is attempted. During the course of model simulation or forecast, other data (including XBT, GEOSAT, or even bogus) can be used in data assimilation. The method of data assimilation depends on the properties of the model and the data being assimilated.

We believe that, although tremendous effort has been devoted to the data set, no one can ascertain how close the analysis is to the truth. On the other hand, although much effort has been spent in developing dynamical models, they are still limited by the numerics used, the scale and the physics involved. Therefore, caution is needed when comparing the DAMEE analysis data and the model simulation results.

Most of the DAMEE data are temperature and salinity. It is very desirable to include the velocity field in the data set. However, it is almost impossible to get enough current meter observations to perform an objective analysis of the velocity field for the entire Gulf Stream Region. One alternative is to take the velocity field from model simulations and compare it with as many in-situ measurements of currents as possible. If a majority of velocity measurements agree with the simulated velocity data at the corresponding model grid points; and the in-situ and remote-sensing data of temperature agree with the model temperature field, we may consider that model's velocity field useful. To achieve this, an iterative process is necessary, and is described below.

The spatial and temporal domains of the SYNOP experiment and DAMEE overlap each other. Thus, the data sets from the SYNOP that fall within the DAMEE time period and inside the DAMEE spatial domain will be of great value in generating a comprehensive data set for modeling and theoretical study. The importance of the SYNOP data set to this task comes from its good coverage of the area adjacent to the Gulf Stream. Figure 58 shows the moored arrays of the SYNOP experiment. The SYNOP data sets include observations from arrays of current meters and inverted echo sounders (IES), moored acoustic Doppler current profilers (ADCP), shipboard hydrography, conductivity-temperature-depth sensor (CTD), expendable bathythermographs (XBT), dropsondes (POGO), expendable current profilers (XCP), RAFOS floats, and IR imagery.

Three moored ADCPs near 37.5°N, 68.5°W were part of the SYNOP Central Array at sites H3, H4 and I2 (Johns and Zantopp, 1991). Measurements were taken from 10 June 1988 through August 1990. They provide month-long continuous measurements of near-surface current for the width of the Gulf Stream for our DAMEE Case 4. RAFOS float data were collected from April 1988 to March 1990 (Anderson-Fontana and Rossby, 1991, also see Figure 59). Thus, it also provides Lagrangian velocity data for DAMEE Case 1, Case 4 and Case 5. Floats were seeded in the Gulf Stream axis and gave us the most important information about the Gulf Stream currents.

If an appropriate model is initialized with the OTIS temperature and salinity fields of Case 4 (begins 30 May 1988) and then assimilates the 5 June OTIS new analysis and all XBTs data collected in the DAMEE and SYNOP data sets, the model velocity field should be ready to compare with

the ADCP data and RAFOS data mentioned earlier by the next OTIS analysis data, 13 June 1988. If both the temperature field and velocity data agree well with observations, this model simulation may be used as a starting point. If not, both the OTIS analysis on 30 May and 5 June need to be adjusted by a trial and error approach and use intermittent (or adjoint) data assimilation of velocity to get the model velocity on 13 June close to observation. If this is achievable, this model can continuously assimilate new XBT, ADCP and RAFOS data between OTIS analysis dates and verify with all observations and OTIS analysis on subsequent OTIS analysis dates. New OTIS analyses may need adjustment before the next cycle. After the whole series of trial and error adjustments from 30 May through 4 July are completed, a continuous simulation is necessary to create a comprehensive data set of all variables.

This kind of complete data set can be used to pursue a theoretical study of the dynamics involved in the growth of Gulf Stream meanders and the formation of rings. Remember, this approach is taken just for convenience, and the findings should always be cross-checked with a detailed study through the analysis of real data.

So, this brings about the planning strategy for future observation programs. By examining the 3-D comprehensive data set, we may detect the different spatial and temporal scales of the Gulf Stream variation and arrange the instruments accordingly in future field programs.

SYNOP Moored Array Program

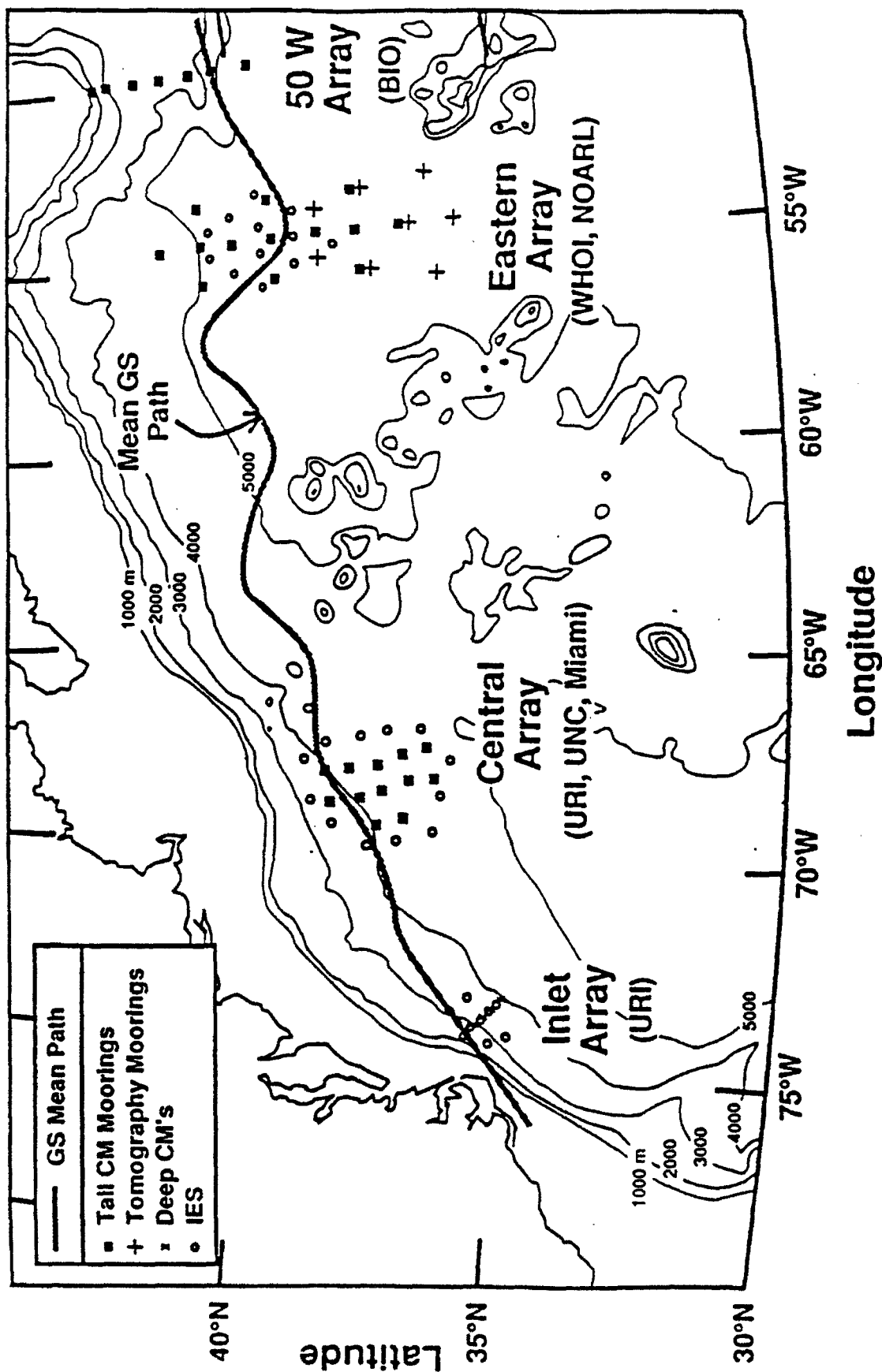


Figure 58. Moored arrays of the SYNOP experiment.

RAFOS Floats in the SYNOP Experiment 1988-1990

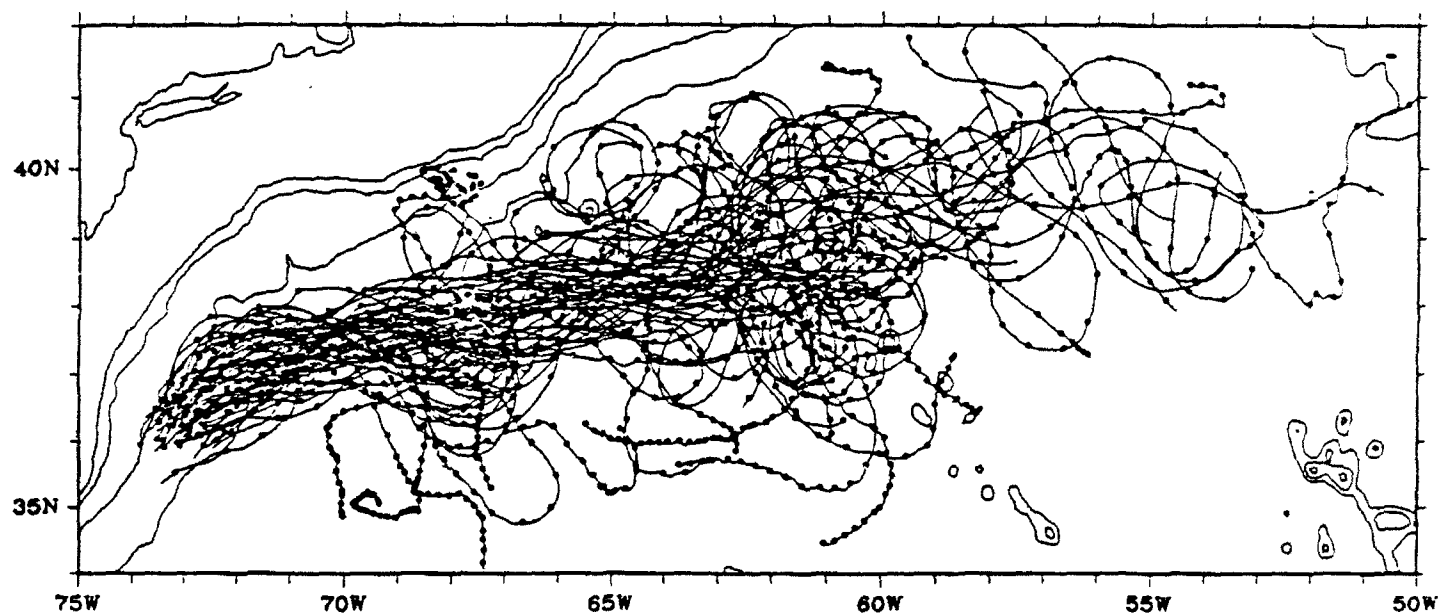


Figure 59. RAFOS float trajectories in the SYNOP experiment.

VII. Summary

The goals of DAMEE were: (1) to foster good COMMUNICATION between university ocean modeling groups and the Navy ocean modeling group, (2) to provide an opportunity for university and Navy research scientists to EVALUATE their models and data assimilation techniques, and (3) to COMPARE the strength of different models under a uniform configuration. The concept of DAMEE is unique in the history of ocean modeling and data assimilation research.

Based on the experiences of the participating groups, we realized that the success of applying a primitive equation model in forecast mode is determined, in large part, by how the model is initialized, which data are assimilated, and how the subgrid scale processes are parameterized. In fact, the goal of DAMEE was not to recommend a specific model, but rather to point out the apparent success or failure of various techniques within the initialization schemes and assimilation methodologies. Toward this end, the DAMEE showed that the preparation of a best-possible nowcast (analysis) is a key component of forecast ability. The significant amount of experience dealing with various aspects of data preparation is the harvest shared by all participants.

The preparation of the DAMEE data set consisted of a series of processes: (1) collection of observational data, (2) analysis and interpretation, (3) interpolation using the Optimum Thermal Interpolation System (OTIS) package, (4) quality control and reanalysis, (5) data archiving and software documentation.

The data products from these processes include a time series of 3-D fields of temperature and salinity, 2-D fields of surface dynamic height, 2-D bogus information of the Gulf Stream and Rings system, 2-D MCSST fields and XBT profiles. This DAMEE data set is a big asset to the oceanography research community. To date, it is the most detailed and high-quality data for mesoscale modeling, data assimilation, and forecasting research. By skillfully applying this data set to data assimilation, using the appropriate model, it can generate a comprehensive data set of model variables which may be treated as close to observations and used in future theoretical research and observation plans.

It is intended to make this data set easy to access. Thus, the hierarchy of the data directories and software are also provided. An ideal way to make it user friendly is to put all data, documents and software into a few CD-ROMs.

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